1986

Effects of Straw Residues on Soil Erosion (Rainfall).

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8710574

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EFFECTS OF STRAW RESIDUES ON SOIL EROSION

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EFFECTS OF STRAW RESIDUES ON SOIL EROSION

A Dissertation

Submitted to the Graduate School of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Interdepartmental Program of Engineering Science

by
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December 1986

ACKNOWLEDGMENTS

I gratefully acknowledge the support and cooperation received from my employer, Agricultural Research Service, USDA National Sedimentation Laboratory, Oxford, Mississippi. Special thanks for encouragement and support are due my supervisor, Dr. C. K. Mutchler, Research Leader of the Sediment Yield Unit of the USDA National Sedimentation Laboratory. Appreciation is expressed to the other many members of the staff of the Laboratory who provided assistance with instrumentation, data processing, drafting, typing, manual labor, etc.

I also gratefully acknowledge the support and cooperation received from the Agricultural Engineering Department (my major department) and all other departments of Louisiana State University that were involved in the interdisciplinary program. Special appreciation is expressed to Dr. R. L. Bengtson, chairman of my graduate committee for his help and guidance throughout the graduate program. Appreciation is also expressed to the other members of my graduate committee for their interest, patience, and encouragement.

Finally, appreciation is expressed to my parents and other close relatives for continued moral support, which of course they have always abundantly given throughout my life.

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ABSTRACT

The objectives of this study were to determine the effects on interrill erosion and runoff of: (1) various rates of surface straw, (2) various rates of incorporated straw, and (3) various rates of incorporated straw over two levels of surface straw. A randomized block design, a completely randomized block design and a 4x2 factorial using a randomized block design was used for objectives 1, 2 and 3, respectively.

Grenada silt loam soil was placed in a 0.91 by 0.91-m soil pan with a central 0.46 by 0.46-m test area. The soil pan was on 2.5% slope. Simulated rainfall at 64 mm/hr was applied in a series of runs for each treatment. The series of runs consisted of an initial 60-minute "dry" run followed in 24 hours by two 30-minute runs ("wet" and "very wet" runs) separated by a 30-minute interval without rainfall.

Increasing rates of surface straw from 0 to 8 t/ha resulted in decreased rates of soil loss, but caused little change in runoff. There was insufficient evidence to conclude that incorporated straw affected any changes in either soil loss or runoff for any level of surface straw.

Incorporated straw had no effect on runoff or soil loss in this study because of the surface sealing of the Grenada silt loam soil. Research was limited to the interrill component of the erosion process. Future research should include studies on the effects of incorporated straw on rill erosion.

EFFECTS OF STRAW RESIDUES ON SOIL EROSION

by

Keith C. McGregor

INTRODUCTION

Advances in chemical weed control technology in recent years have allowed many farmers to either eliminate or minimize tillage practices. No-till farming, in which crops are planted in residues left from the previous season, is gaining acceptance throughout the country. This practice has the greatest potential for erosion control from among all the management systems presently available. Erosion is reduced because of protective cover left on the surface. No-till also reduces erosion because of minimum disturbance of the soil. The crop is planted in narrow slots opened in the soil by rolling coulters or small chisels, and no secondary tillage is done.

More research is needed on how to manage crop residues for maximum protection in no-till systems. Research is also needed in managing crop residues in reduced-till systems that may be applicable in areas where no-till may not be an acceptable management alternative. Continuation of no-till also may not be desirable because of unique problems with insect populations, crop diseases, and uncontrolled growth of weeds over a period of many years.

Research data are needed to quantify the amounts of residue that should be incorporated or left on the surface for various reduced tillage systems. Reduced tillage systems may consist of one or more operations with implements such as disks, chisels, and "do-all" cultivators. These systems may also consist of separate operations with two or more implements. More research information is needed on how to manage crop residues for erosion control during the seedbed preparation and early growing period when the land is particularly vulnerable to erosion.

Statistical probabilities based on historical records can be given for durations, amounts and intensities of rainfall for different areas of the country. But no appreciable changes can be made in rainfall characteristics. Soil can be classified according to its susceptibility to erode; however, affecting significant changes in the intrinsic erodibility of soils is not presently economically feasible. It is also not practical to lower slope gradients which are too steep. Effective slope lengths can be reduced in some field situations by installation of terraces.

The most efficient way to reduce soil erosion of agricultural land is to use a combination of tillage and cropping practices that reduces the amount and frequency of tillage as much as possible while maximizing the amount of crop residues left on the soil surface. Any change in cultural practices that provides increased protective cover almost always reduces soil erosion.

Rainfall and runoff are driving forces that result in the erosion of agricultural land. Climate is thus a major factor affecting the erosion process. Potential for erosion varies across the country depending upon the distribution and intensity of rainfall throughout the year. Some areas have more rainfall than others. Erosion can be reduced by selecting cropping and tillage practices that minimize the effect of the erosive storms. Protective residue and/or canopy cover and as little soil disturbance as possible is needed during periods when the most erosive storms are expected to occur. Continued research that quantifies erosion under varying climatic, topographic, soil type, tillage and cropping management conditions will ultimately result in improved erosion control recommendations.

There are generally two approaches to soil erosion research. One approach utilizes field plots and small watersheds under natural rainfall. The period of data accumulation tends to become very lengthy; usually a minimum of three years is required to ensure meaningful results. Measurements of many variables may be made, but controls established for only a few. Another approach makes use of rainfall simulators with either small plots located in field areas or soil pans inside the laboratory. The latter approach allows control over more variables with shorter periods of data accumulation. Both approaches are useful. More sophisticated equations or adaptation of presently used equations for wider and more accurate prediction can be made as new information gained from both research approaches is proven applicable for different regions, climates and soils.

Small laboratory studies increase knowledge of the basic mechanics of soil erosion, but application of their results to large scale prediction of soil loss is difficult. Regardless of the nature of a laboratory experiment, field situations can never be entirely simulated. Furthermore, duplication of experiments with changes made in some of the controlled variables show the interactive nature of such variables. There are so many variables and combination of variables to be considered that progress toward practical soil loss prediction with results from laboratory experiments is very slow. Nevertheless, such studies are valuable, particularly in learning more about the effects of selected variables on soil erosion in interrill areas.

Laboratory experiments can provide information on the effects of different rates of residue incorporation on erosion as well as the effects from different surface to incorporated residue ratios. This information could be a beginning point for designing specific reduced tillage systems for specific ranges of acceptable soil losses. The Soil Conservation Service generally recommends a tolerance limit for soil loss that ranges from about 4 to 11 tons per hectare (t/ha). These tolerance limits are based on the amount of erosion that can occur while the productivity of the land is sustained.

Specific objectives of this research study were:

1. To determine the effects of different rates of surface straw residue (0 to 8 t/ha) on runoff and soil loss.
2. To determine the effects of different rates of straw residue (2.2 to 9.0 t/ha) incorporated in the top 9 cm of soil on runoff and soil loss.

3. To determine the effects of different combinations of surface straw and incorporated straw on runoff and soil loss.

REVIEW OF LITERATURE

Universal Soil Loss Equation

An understanding of the role of placement of crop residues in controlling erosion can best be obtained by first examining some of the major factors affecting erosion. The erosion process is extremely complex and is influenced by many variables. Fortunately, a lack of understanding of all the factors influencing the erosion process does not prevent utilization of a minimum number of factors in such a way that practical and widespread application for erosion control can be made. The universal soil loss equation (USLE) has only a few parameters, but has wide applicability (Wischmeier and Smith, 1965). Presentation of the USLE is a good place to begin an examination of the soil erosion process.

An attractive feature of the USLE is its simplicity. The USLE contains only six factors, but it has proven to be a dependable guide for resource conservationists in making practical recommendations for long-range planning. Interaction occurs with many of the variables that influence erosion. These interaction effects are lumped together in the USLE. As knowledge of separate effects of different variables increases, more sophisticated and accurate prediction equations can be developed.

The USLE contains an erosion index (EI) factor and a cropping and management (C) factor which can be evaluated on the basis of local climatic and crop cultural conditions. Development of these factors allowed application of the USLE to be made in different regions of the country, and thus is the reason it became known as a "universal" equation. The USLE provides a practical and simple method for estimation of soil loss under varying conditions.

The USLE, developed by Wischmeier and Smith (1965), is:

$$A = R\ K\ L\ S\ C\ P$$

where A is the computed soil loss per unit area per time. The unit of measure is the same as that of K times R.

R, the rainfall factor, is the number of erosion-index (EI) units in a normal year's rainfall. The EI of each storm is the kinetic energy (MJ/ha) of storm rainfall times the maximum 30-minute intensity (mm/h) of storm rainfall.

K, the soil erodibility factor, is the soil loss (t) per unit of erosion index (MJ•mm/ha•h) per unit of area (ha) for a specific soil in cultivated continuous fallow, on a 9-percent slope 22.1 m long.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 22.1 m length on the same soil type and gradient.

S, the slope-gradient factor, is the ratio of soil loss from the field gradient to that from a 9-percent slope.

C, the cropping-management factor, is the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which factor K is evaluated.

P, the erosion-control practice factor, is the ratio of soil loss with contouring, stripcropping or terracing to that with straight-row farming up-and-down slope.

The rainfall characteristic parameter (EI) was found to be the best single estimator of the erosive potential of rainfall. A primary agent in the detachment and removal of soil from interrill areas is raindrop splash (Mutchler and Young, 1975). The amount of raindrop splash is partially dependent on raindrop size, which in turn is a function of rainfall intensity. The EI parameter thus combines the effects of the kinetic energy of different size drops throughout different storms as well as periods of high intensity on raindrop splash.

An increase in kinetic energy of storm rainfall causes an increase in the ability of falling raindrops to break down soil aggregates. Soil particles are dislodged from the aggregates and moved by raindrop splash. Runoff entrains and transports the detached soil material more easily than the original aggregates. An increase in soil moisture, erosion of soil particles, and formation of a surface seal affects the detachment of soil by raindrop impact (Foster and Meyer, 1975). The soil erodibility (K) factor in the USLE partially reflects changes throughout the year in these types of occurrences for different soils.

Although raindrops serve as the major source of detachment and transport of soil from interrill areas, the amount of soil eroded from a field area is limited by the transport capacity of runoff. Runoff amounts are of course directly affected by rainfall amounts, but are also influenced by any soil properties that affect the infiltration rate of water through the soil profile. Antecedent soil moisture content, amount and type of protective cover, slope gradient and slope length also affect runoff amounts.

General Observations about the Erosion Process

Land slope, rainfall characteristics, cover and management may influence the rate of soil erosion more than properties of the soil itself. Even when these factors are identical, some soils erode more readily than others. Wischmeier and Smith (1965) said this difference, due to properties of the soil, is known as soil erodibility. Soil properties reported to influence erodibility by water are: (1) those that affect the infiltration rate, permeability and total water capacity, and (2) those that resist the dispersion, splashing, abrasion, and transporting forces of rainfall and runoff.

Erosion occurring on areas between rills is known as interrill erosion. It depends on both raindrop impact and thin film flow. Rill erosion occurs along flow concentrations in many small but definable channels. These channels may be caused by topographic irregularities, tillage marks, surface roughness, or by the erosion process itself. Rill erosion depends on hydraulics of flow in the rills (Foster et al., 1984).

Plant canopy reduces the velocity of falling raindrops. Raindrop kinetic energy is also reduced since the remaining fall distance is usually less than required for terminal velocity. Surface cover provided by crop residues is more effective than plant canopy in reducing erosion (Foster and Meyer, 1977). Erosion by raindrop splash is essentially eliminated when raindrops are intercepted by material on the soil surface (Wischmeier, 1975).

Meyer and Mannering (1967) observed that the erosion process begins when raindrops first strike the earth's surface and detach soil particles by splash. They stated that the erosive potential of rainfall is directly related to the raindrop fall velocity, size distribution and total mass at impact. They further observed that when the soil surface is not well protected by vegetation or other cover, raindrops enhance soil erosion by: (1) breaking soil crumbs and aggregates into smaller more easily transported sizes, (2) reducing infiltration rates through soil surface sealing, (3) splashing soil particles dominantly downslope or to runoff channels, and (4) increasing the sediment-carrying capacity of runoff through splash turbulence.

Meyer and Mannering (1967) reported that the resistance of a soil to erosive forces depends on the size, shape, density, cohesiveness, etc. of soil particles, plus the soil's macrostructure (cloddiness) as it affects ease of detachment from the soil mass and transportation by runoff. The smaller and rougher particles are generally less easily detached but more easily transported. Meyer and Mannering stated that most of the above mentioned factors also affect infiltration and surface storage characteristics. Loam and silt loams were reported to generally erode more easily than soils with high clay or sand contents, because they are most susceptible to sealing and are readily detached and transported.

Particle size distribution, density and degree of aggregation also affect soil detachment and subsequent erosion. Silt sized particles erode more easily than clay or sand-size particles. Silt and clay are often eroded together in the form of sand-size aggregates. Cohesive soils usually produce sediment that consists of both primary particles and of soil aggregates. Non-cohesive soils usually produce sediment composed of primary particles (Young, 1980).

Young (1984) thought of soil erosion as the end result of two physical processes - the detachment of soil particles from a soil mass and the transport of these particles from the point of detachment. He reported that detachment occurring in small channels or rills is the result of flowing water while detachment in the nearly level areas between rills is the result of raindrop impact.

Young (1984) noted that current efforts are being made to represent the erosion process with sediment detachment equations that treat the rill and interrill phases separately. He felt such equations require soil erodibility factors that provide an indication of the relative importance of rainfall energy and runoff energy for detaching soil particles. Young and Onstad (1982) stated that an effective soil erodibility factor indicating susceptibility of soil to interrill erosion must include the effects of degree of aggregation, amount and type of clay present in the soil, and aggregate stability. Such erodibility factors would reflect optimum aggregate size for resistance to raindrop impact forces, aggregate strength, and resistance of the aggregate to impact and rupture forces and subsequent aggregate breakdown.

Young and Onstad (1982) felt an effective erodibility soil factor indicating the susceptibility of soil to rill erosion must include the effects of organic matter content, aggregate density and aggregate stability. Each of these properties were related to susceptibility to rill erosion as follows. Organic matter content affects the ease of wetting of soil aggregates, and thus also affects their resistance of break-down under immersion. As organic matter increases, soil aggregates in flowing water tend to wet up more slowly when immersed in flowing water. Since aggregate stability is commonly measured using a standard wet sieving procedure, it more closely approximates slaking forces caused by flowing runoff water than by raindrop impact.

Epstein and Grant (1971) noted that loose unprotected aggregates of cohesive soils (loams, silty clay loams and silt loams) are easily detached, broken down, and washed away at the beginning of storm rainfall. They also observed that surface seals often develop rather rapidly while infiltration is reduced to a constant rate. Epstein and Grant believed that continuation of soil loss after the development of a surface seal means that detachment of soil particles from the surface seal is taking place. They reasoned that the detachment process for cohesive soils after formation of a surface seal is caused by thin layer shearing accompanied by the continual formation of a new consolidated seal.

Physical changes often occur in the upper few mm of the soil following wetting and subsequent drying of soil surfaces (Edwards, 1976). The surface becomes denser, and the size and amount of large pores decreases. These changes result in a reduction of surface permeability to water, air and plants. Edwards (1976) referred to this compacted surface layer, which can be usually distinguished from relatively undisturbed soil below, as a soil crust. Such crusts reduce plant emergence for a short time after planting, but continue to limit infiltration thus increasing runoff long after crop emergence. Tilled soils that are unprotected by vegetative cover usually have the most severe crusting problem (Edwards, 1976).

Epstein and Grant (1971) determined soil crust strength by modulus of rupture and penetrometer tests. Collamer silt loam, Marshall silty clay loam, and Bruxton silt loam soils were screened through a 9.5 mm sieve and placed in 30.5 cm-square pans to a depth of 15 cm. Simulated rainfall was applied at two different intensities, 51 and 89 mm per hour. Drop sizes of 3.2 and 5.1 mm were used with both intensities. The modulus of rupture at intensities of 51 mm per hour ranged from 0.16 to 0.79 bars and 1.00 to 2.04 bars for drop sizes of 3.2 and 5.1 mm, respectively. The modulus of rupture for intensities of 89 mm per hour ranged from 0.16 to 0.60 and 0.74 to 1.57 bars for drop sizes of 3.2 and 5.1 mm, respectively, For each given drop size, crust strength generally decreased with an increase in intensity and crusts formed under the 3.2 mm drops were weaker than those developed under the 5.1 mm drops. Epstein and Grant also obtained similar relationships using rupture stress measurements with a penetrometer. They concluded that seals and crusts are formed as a result of raindrop impact and seals are continuously being removed by turbulent water. Formation of weaker crusts under higher rainfall intensity was attributed to a faster removal of the seal due to greater turbulence.

Textural analysis of the seals showed that the clay content of the 0 to 2 mm crust was essentially the same as that of the underlying soil, but the clay content within the 0 - 0.5 mm surface crust was less than in the soil while the silt content was higher. The clay content of the 0 to 2 mm crust did not change with increase in duration of rainfall from 10 to 30 minutes, but the clay content in runoff was slightly higher than in the soil or crust. Epstein and Grant believed that the formation of a surface seal prevented further washing-in of fine materials and thus no further build-up of crust after the initial crust formation. The formation and reformation of seal was a continuous process without any change in the textural content of the crust below the seal.

Soil erosion is a dynamic process. The most marked changes at the soil surface occur when the surface is unprotected by any type of cover. Considerable research has been conducted on the effect of crop residue, particularly surface residues, in reducing erosion. Wischmeier (1973) reported that studies on field plots and small watersheds show that conservation tillage practices can be highly effective for control of erosion, but their effectiveness differs substantially with the type of practice and quality of management. He felt the dominant factor in determining effectiveness is the amount and distribution of crop residues remaining on the soil surface.

Wischmeier (1973) stated that partial covers of residues are more likely to fail when the shear stress of flow increases appreciably. He noted that the probability of failure increases where the slope gradient becomes steep, where the runoff rate becomes large because of a long slope or a concentration of runoff, or where the product of slope gradient and percent slope becomes large. He observed that incorporated residues tend to improve infiltration and thereby reduce runoff, but that incorporated residues mixed into the surface by operations such as chiseling or disking are less effective than those left on the surface.

Wischmeier (1973) gave some results from a study of 678 plot years of data for conventional corn systems. Runoff averaged 40% less where residues were mixed into the soil each year by plowing than when stover was removed at harvest. A ton of corn residue left on the surface reduced soil loss about 65%, whereas each ton of residue incorporated into the surface reduced soil loss about 12%. Surface residues reduced runoff by reducing surface sealing and crusting. Soil loss was reduced because of reduction in the detachment capacities of both rainfall and runoff. Partial covers of surface residues reduced runoff velocity and thus the shear stress and carrying capacity of runoff. Reduction in runoff velocity also increased the depth of the cushioning film of water on the surface during rainfall.

Meyer and Mannering (1963) reported that thoroughly incorporated residues can materially improve the soil condition and infiltration characteristics, but that surface residues are more effective for erosion control. They felt that mechanical treatment of surface residues, such as spreading and shredding, often provides the most effective surface cover. Crop residues were reported to have an important potential for better erosion control on intensively cropped, sloping soil.

Meyer and Mannering (1963) gave several reasons why crop residues reduce erosion. Residues dissipate a part of the energy of the falling raindrops and/or the energy of flowing runoff. Less energy is available for detachment and transport of soil particles. The amount of dispersed soil available to be removed in runoff is reduced. Runoff amounts are reduced because of the prevention of soil splash, which would tend to close soil pores used for infiltration. Plant residues form small diversions and detention reservoirs that slow runoff velocity and reduce soil loss. Surface water held in these areas also dissipates raindrop energy. Small rates of surface residues do not greatly reduce raindrop impact, but runoff velocity is decreased. The dominant factor in erosion control with higher rates of residue cover is the raindrop energy dissipation.

Foster and Meyer (1977) stated that the effectiveness of soil surface cover depends on it staying in place and not being washed away or allowing rill erosion underneath the cover. Foster and Meyer observed that material on the soil surface slows runoff and increases flow depth. Increased flow depth also acts as a protective cushion and further decreases soil detachment by raindrops. A reduction in shear stress of runoff due to material on the surface also results in less detachment of soil particles. Onstad (1984) noted that water covered areas above a certain depth probably do not erode because the layer of water cushions the raindrop. Depressional areas also serve as sediment traps for soil being eroded from higher exposed soil surfaces.

Research Results from Laboratory Experiments

Almost all laboratory experiments that involve measurements of soil erosion have been conducted using simulated rainfall. The following examples include some significant research results and also illustrate the methodology often used in laboratory studies of soil erosion.

Harmon and Meyer (1978) used a rainfall simulator and a 122 by 122 cm pan to study the effects of cover, slope and rain intensity on soil erosion. The test plot consisted of a 61 by 61 cm area in the center of the pan, which was separated from the surrounding border areas with vertical metal strips. Soil was placed in the pan in increments of about 2 cm to a depth of 8 cm. Each layer of soil except the top 2 cm was hand compressed. Water that infiltrated through the soil and the underlying cotton fabric, screen wire and wire mesh was allowed to exit via outlets in the bottom of the pan.

A randomized block design was used to analyze results for various combinations of surface straw rates, percent slopes and rainfall rates. An initial rain of 60 minutes (dry run) was followed the next day by two 30-minute runs separated by a 15-minute interval with no rainfall. These two runs were called wet and very wet runs. A Providence silt loam soil was used which had been collected at a tillable moisture content and sieved through a 12-mm mesh screen. Rainfall was applied at a rate of 5.8 cm/hr.

Runoff from a 2.5% slope with no protective cover on the soil was 34, 22 and 24 kg/m^2 for dry, wet and very wet runs, respectively. Soil loss was 288, 120 and 168 g/m^2, respectively. No measurements of runoff and soil loss at 2.5% slope were made for any rates of surface straw, however, the values for bare surface are presented here because these rates can be directly compared to results obtained in this dissertation study.

Runoff from bare soil at 6% slope was 35, 22 and 22 kg/m^2 for dry, wet and very wet runs, respectively. With a cover of 2 t/ha of straw, runoff was 28, 21 and 22 kg/m^2 for dry, wet and very wet runs, respectively. Thus the application of 2 t/ha of wheat straw did not appreciably affect runoff. However, an application of 8 t/ha of straw reduced runoff to 1, 6 and 10 kg/m^2 for the dry, wet and very wet runs, respectively.

Surface straw was effective in reducing soil loss in the runoff from the 6% slopes. With the surface left unprotected, soil loss was 412, 153 and 212 g/m^2 for dry, wet and very wet runs, respectively. With an application of 2 t/ha of surface straw, the soil loss was reduced to 142, 77 and 102 g/m^2 for the dry, wet and very wet runs, respectively. Surface straw of 8 t/ha reduced soil loss to minimal amounts of 2, 8 and 11 g/m^2, respectively.

Harmon and Meyer attributed the decrease in soil loss with increases in surface straw to reduction in the amount of soil exposed to rainfall, restriction of movement of water and sediment by residue cover, and prevention of surface sealing. They did not explain, however, why runoff with rates of 2 t/ha of surface straw was not much different from that at 0 t/ha, even though soil loss was greatly reduced.

Lattanzi et al. (1974) studied the influence of mulch rate and slope steepness on interrill erosion. A Russell silt loam (Typic Hapludalf) soil from the plow layer was sieved through a 12-mm mesh screen. Soil was placed to a depth of 8 cm in a 122 by 122 cm pan with a central test area of 61 by 61 cm. Soil was placed in layers of 2-cm increments. Each layer except the last was hand compressed on a small wooden block. Runoff flowed through a slot at the lower end of the test area. Water also drained freely through the soil profile, several layers of cotton fabric and wire mesh to outlets in the soil pan floor. Simulated rainfall was applied at a rate of 64 mm per hour for an initial 60-minute run followed the next day by two 30-minute runs separated by a 15-minute interval without rainfall.

A randomized block design was used in which all combinations of four surface rates of wheat straw mulch and four slope steepnesses were studied. Lattanzi noted that the straw absorbed a relatively minor amount of applied rain and observed no evidence of rilling for any of the runs, even when the surface was left bare. The wetting front rarely reached the bottom of the soil during the 60-minute initial runs for mulch rates of 0, 0.5 and 2 t/ha. Free drainage began about mid-way through the initial run with surface straw rates of 8 t/ha, but there was no noticeable change in runoff rate due to profile saturation.

Table 1 shows the runoff and soil loss for initial, wet and very wet runs for a surface slope of 2%. There was very little change in runoff for surface straw rates of 0 to 2 t/ha. The runoff at a surface rate of 0.5 t/ha was numerically larger than with 0 t/ha, but was not significantly different. Runoff for the 8 t/ha rate of surface straw was about 95, 91 and 86% less than that for 0 t/ha during initial, wet and very wet runs, respectively. The 8 t/ha rate of surface straw practically eliminated soil loss for all runs with a surface slope of 2%. Soil loss decreased rapidly for mulch increases from 0 to 2 t/ha.

Some primary conclusions by Lattanzi et al. (1974) were:

1. Interrill erosion can be virtually eliminated by complete mulch cover, but lesser amounts will greatly reduce soil losses.

2. Interrill erosion is influenced much less by slope steepness than is rill erosion.

3. Interrill erosion is primarily due to raindrop impact.

Table 1. Runoff and soil loss during initial, wet and very wet runs for increasing rates of surface straw on 2% slope in experiments by Lattanzi et al (1974).

Surface Straw	Runoff			Soil Loss		
	Initial	Wet	Very Wet	Initial	Wet	Very Wet
(t/ha)	kg/m^2	kg/m^2	kg/m^2	g/m^2	g/m^2	g/m^2
0	49.3	28.6	28.4	951	406	400
0.5	50.9	29.9	30.8	602	256	255
2	43.5	27.7	28.9	244	88	84
8	2.5	2.5	4.0	7	2	1

4. Mulch rates that protect the soil from surface sealing can greatly reduce the amount of runoff.

Lang et al. (1984) used 1-m square pans with a rainfall simulator to study the influence of slope steepness (3 and 9%), mulch rate (0, 1.12 and 2.24 t/ha) and antecedent soil moisture condition (dry and wet runs) on runoff and soil loss of mined land topsoils in North Dakota. The topsoils had been stockpiled for later distribution on reshaped spoil material.

Soils were passed through a 1.3 cm sieve, allowed to air dry, and placed to a depth of 8 cm in four layers. Soil in the first three layers was uniformly packed with a miniature soil compaction hammer. The top layer received no compaction. It was not clear whether the resulting bulk density of 1.18 g/cm^3 referred to the entire profile or to the top layer.

The experiment was arranged into a randomized factorial design with two replications of all combinations of soil types, mulch rates, and moisture conditions. Rainfall was applied at a rate of about 51 mm per hour, which was the 25-year return frequency for 1-hour duration rainfall. Rainfall was applied for one hour on initially dry soil and followed in 24 hours with another 1-hour application. Runoff was collected from an inner 61 by 61-cm test area of the soil pan. The floor of the soil pan was constructed to allow unrestricted drainage of water that infiltrated through the soil.

Lang et al. found that mulch rates of 1.12 and 2.24 t/ha reduced runoff in dry runs from that from bare soil treatments, when averaged over all soils and slopes, by 17 and 28%, respectively. Mulch rates had no effect on runoff during wet runs.

Infiltration and surface detention with no mulch nearly equaled the application rate during the first 10 minutes of dry runs. Runoff was then initiated and increased rapidly until it leveled off to about 70% of the application rate at about 20 minutes into the dry runs. With 2.24 t/ha of surface mulch, runoff began at about 20 minutes and increased until it approached the application rate near the end of the initial 1-hour run. Thus the mulch application delayed initiation of runoff, but the runoff rate at the end of the run was greater than that with no mulch.

Lang et al. felt that formation of a surface seal by raindrop impact reduced infiltration and initiated runoff on the bare surfaces. They felt the leveling off of runoff rates after 20 minutes during the dry runs may have been due to removal of the surface seal by turbulent surface flow. Research by Epstein and Grant (1971) was referenced to reinforce this concept, although it was pointed out that Epstein and Grant believed that the formation and reformation of a seal is a continuous process. Lang et al. credited mulched surfaces for dissipating energy of raindrops, reducing surface seal formations and increasing surface detention as splashed soil particles formed small dams against small pieces of straw.

During the 1-hour wet runs, runoff for all treatments began immediately and increased rapidly to a constant rate, except that runoff at 10 minutes of the wet runs was slightly greater than thereafter. Lang et al. believed mulch effectiveness on runoff during the wet runs was due to a reduction in hydraulic conductivity caused by crusting and collodial swelling.

Soils obtained near Underwood, North Dakota represented a mixture of the top 46 cm of Arnegard and Bowbell soil (fine-loamy, mixed Pachic Haploborolls) with a history of cultivation. The texture was about 23, 52, and 25% clay, silt and sand, respectively. The soil contained about 2.5% organic matter. The aggregate stability and dispersion rate was about 32.2 and 32.7%, respectively.

When placed on 3% slopes, soil loss averaged 330, 130 and 70 g/m^2 during dry runs and 350, 180, and 170 g/m^2 during wet runs for mulch rates of 0, 1.12 and 2.24 t/ha, respectively. Runoff was about 30, 22 and 17 kg/m^2 during dry runs and about 48, 40 and 48 kg/m^2 during wet runs for the respective mulch rates.

Kramer and Meyer (1969) conducted laboratory experiments in which fiberglass electrical sleeving was used to simulate straw rates of 0.28, 0.56, 1.12 and 2.24 t/ha. Glass spheres averaging 33 and 121 microns in diameter simulated silt size and sand size soil particles, respectively. A factorial experiment was used to test erosion rate and runoff velocity for these mulch rates, four different slopes and three different slope lengths.

Silt-size particles generally eroded much more under identical treatments than did fine-sand size particles. Mulch rate, slope steepness and slope length each significantly affected the rate of erosion and runoff velocity. Slope steepness and mulch rate had the greatest effect on erosion and runoff velocity, respectively; however, there were significant interactions among the treatments.

Kramer and Meyer concluded that compared with no-mulch conditions, mulch rates of 0.56 to 2.24 t/ha greatly reduced the erosion rate and runoff velocity for a wide range of slope steepnesses and lengths. Mulch rates of 0.28 and 0.56 t/ha effectively reduced erosion of fine-sand size but not silt-size particles. Erosion of silt-size particles was actually increased for some combinations of treatments levels. For example, with a slope of 6% and a slope length of 30.5 m, the erosion rate with 0.28 t/ha of mulch was about 3.2 times that for no mulch for the silt-size spheres. When higher mulch rates were applied, there was enough total resistance to runoff to also reduce erosion for the silt-size spheres.

Research Results from Field Experiments

Field plots under natural rainfall or under simulated rainfall are also used to study the effects of surface residues on soil erosion. Erosion from such areas may include both rill and interrill erosion. A few examples will now be given of simulated rainfall studies of erosion from larger plots located in field areas.

Mannering and Meyer (1963) studied the effects of applied wheat mulch on infiltration and erosion of a highly permeable Wea silt loam soil using 3.7 by 10.7 m plots. Plots were on 5% slope. Wheat straw, about 15 to 25 cm in length, was applied by hand to fallow soil that had been disked three times to a depth of 5 to 8 cm. Straw rates of about 0.6, 1.1, 2.2, 4.5 and 9.0 t/ha provided 40, 60, 87, 98 and 100% ground cover respectively. A randomized block design was used with two replications of each treatment.

A series of simulated storms was applied with an intensity of 64 mm per hour. There was an initial 60 minutes run at existing moisture conditions followed 24 hours later by two 30 minute runs separated by an interval of 15 minutes. After an additional 24-hour period, there was another 30 minute run.

Total runoff decreased with increasing rates of mulch up to 4.5 t/ha, at which point nearly all of the applied water moved through the soil profile. Higher rates of mulch prevented a surface seal and allowed water to move through the highly permeable soil. Total soil loss was reduced from 26.9 t/ha for 0 t/ha of straw to only 6.7 and 2.2 t/ha for the 0.6 and 1.1 t/ha rate of surface straw, respectively. Total runoff from the series of storms was 7.2, 6.4, 4.0, 0.8, 0.2 and 0 cm for straw rates of 0, 0.6, 1.1, 2.2, 4.5 and 9.0 t/ha, respectively. Soil losses were 28, 7, 3, 1, 0, and 0 t/ha, respectively.

Mannering and Meyer observed that straw mulch created barriers and obstructions over or around which runoff had to move. A reduction in velocity of flow also caused a decrease in particle detachment and transport capacity of the runoff.

Meyer et al. (1970) conducted a similar study on a moderately eroded Fox loam soil. The permeability of the soil was classified as moderate to slow. Following the harvest of oats, all loose stubble and surface residues were removed from test plots. A spike-tooth harrow was used to break the surface crust of the soil. Plots were on slopes that averaged 15%. Data from slopes that deviated from 15% were adjusted, using slope factors from the USLE, to represent results from 15% slopes. Plot dimensions and straw rates remained the same as in the study by Mannering and Meyer. Simulated rainfall was applied at an intensity of 64 mm per hour during an initial 60-minute run followed the next day by two 30-minute runs separated by a 15-minute interval.

An analysis of variance indicated that the effect of rates of surface straw on soil loss was significant at the 1% level. Effects of rates of residue on runoff, infiltration amount, and end infiltration rate were significant at the 5% level, but only for the initial run.

A summary of runoff and soil loss for the different rates of surface straw are presented in Table 2. Surface straw rates of 0.6 and 4.5 t/ha reduced soil loss during initial runs from that with 0 t/ha by about 73 and 97%, respectively. Reduction in soil loss for the total series of runs for these straw rates was about 68 and 96%, respectively. A large reduction of soil loss was obtained with a relatively small application of straw, although complete reduction of soil loss for initial, wet and very wet runs required large amounts of straw. The 0.6 t/ha rate of straw provided only about 34% ground cover.

Table 2. Erosion and runoff data for rainulator study of rates of straw mulch from Meyer et al (1970).

Mulch Rate[a/]	Runoff			Soil Loss		
	Initial	Wet	Very Wet	Initial	Wet	Very Wet
t/ha	cm	cm	cm	t/ha	t/ha	t/ha
0	4.1	2.2	2.4	36.2	13.1	13.0
0.56	3.1	2.2	2.3	9.9	5.1	5.1
1.12	3.6	2.3	2.4	10.1	4.5	4.8
2.24	3.8	2.3	2.5	6.2	2.4	2.9
4.48	2.7	2.0	2.3	1.2	0.6	0.7
8.96	3.0	2.2	2.5	0.9	0.4	0.2

a/ Ground cover was 34, 49, 71, and 92% for the 0.56, 1.12, 2.24 and 4.48 t/ha rates, respectively. Ground cover for the 8.96 t/ha rate was greater than 95%.

Numerical differences in runoff were very minimal, even though the analysis of variance showed a significant effect of surface straw on runoff. There was a 24% reduction in runoff for the 0.6 t/ha straw rate as compared to 0 t/ha; however, the reduction in runoff for the 1.12 and 2.24 t/ha surface rates of straw was only about 12 and 7%, respectively. The small magnitude of runoff values caused these percent reductions to be very negligible as far as any potential effect in reducing soil loss. Runoff values during wet and very wet runs showed no significant differences for the different rates of straw. There was little change in runoff velocities beyond the first reduction of about 49% obtained with the 0.6 t/ha of surface straw. The primary effect of higher rates of surface straw was the reduction in rainfall impact energy.

The authors noted that runoff followed very tortuous paths on mulched plots, thus decreasing the effective slope steepness. Straw segments perpendicular to the slope also served as "sediment traps" where detached soil accumulated and developed a miniature staircase or benching appearance.

Van Liew and Saxton (1983) conducted tests on 10 m long plots in which rills were preformed in the plots by pressing a garden hose into the soil surface. One treatment consisted of a bare soil in which all straw stubble from the previous year's harvest was removed. A second treatment consisted of about 4.7 t/ha of existing straw from the previous year's crop incorporated into the upper 20 cm of soil with a roto-tiller. A third treatment was identical to the second except that straw was added such that a rate of 9.4 t/ha was achieved. The soil was a Palouse silt loam, which contained about 11, 71, and 18% clay, silt and sand, respectively.

Water was introduced above the upper end of each rill to simulate two flow rates of about 0.5 and 0.10 m^3 per meter of rill length. Experiments were conducted during a 4-hour period on slopes of 9, 18 and 23%, respectively. Garden sprinklers were used for two hours on the day before test runs to consolidate and wet the soil to a depth of about 10 cm.

There was little infiltration during runs, with runoff rates of about 95% of the applied rate for the zero and medium residue treatments. Infiltration rates on the high residue treatments were characterized by a small exponential decay. Medium and high residue rates reduced rill erosion rates to 60 and 85% of that with no residue.

Van Liew and Saxton concluded that the incorporated straw reduced the flow's shear stress, acted as a binding agent to reduce the susceptibility to shear stress, and provided miniature grade control structures in the rill channels that served as depositional sites for detached soil. Their results suggested that tillage practices that incorporate residue into the tilled soil layer can substantially reduce soil loss from rill erosion. Unfortunately, their studies were not complemented with results of runoff and soil losses from interrill areas with incorporated residues. Their results were also limited in that the effect of rainfall on the flow and transport capacity of runoff was not considered.

Mulch Factor as a Function of Percent Ground Cover

Wischmeier (1973) defined a mulch factor for use in estimating soil loss as being equal to the ratio of soil loss with a given percentage of mulch cover to the soil loss with no mulch. He presented curves in which the mulch factor decreased with increases in percent cover and for which the effect of varying percentages of cover by plant canopy were also included. Relationships were not described in mathematical terms, but the following equation closely approximates his curve for mulch factor (MF) as a function of percent ground cover (GC) when there is no plant canopy:

$$100\ MF = 93.68 - 1.69\ GC + 0.008\ (GC)^2$$

This equation was obtained by selecting MF and GC values from Wischmeier's plotted curve and can be used for ground cover that exceeds a lower limit of about 5%. The mulch factor represents both the rill and interrill components of the erosion process.

Cogo et al. (1984) stated that the mulch factor may be expressed as:

$$F = e^{-bm}$$

where F is the mulch factor, m is percent residue cover, and b is a regression constant.

Cogo et al. used simulated rainfall on 3.0 by 10.7 m plots to obtain data to evaluate the mulch factor. Rainfall intensity of 64 mm per hour was applied during a 60-minute initial run, and followed in 24 hours by two 30-minute runs separated by a 15-minute interval.

Cogo et al. computed b values for five tillage and cropping management systems. Tillage treatments included no-till, fall moldboard-plowing with disking, spring sweep tillage only, and summer sweep tillage. Soybean and corn residue cover ranged from 2 to 100% and was either spread evenly on the surface after tillage or partially incorporated during tillage. Wheat residue cover ranged from 1 to 100% and consisted of either wheat stubble or wheat stubble plus straw. Wheat straw residue was either left on the surface for no-till, or anchored from partial incorporation by sweep tillage.

Cogo et al. observed that the effects of surface roughness and cover interacted, but the effect of residue cover was greater than the effect of surface roughness for high values of residue cover. A roughness index was defined as the standard error among logarithms of surface elevations obtained with a 102-cm microrelief meter with pins spaced on a 5.1 cm grid.

Mannering and Fenster (1977) noted that the effectiveness of crop residues in controlling erosion include the type of crop, the amount and type of residues produced, removal or non-removal of residues, and tillage effects on residue placement. Quantity, distribution, and durability of residues vary for different crops. Corn residue amounts are normally higher than residues from small grain, soybeans, cotton, and tobacco. Mannering and Fenster stated that small grain residues are superior to corn stalks for erosion control. The small diameter of the straw means more of the ground surface is covered even though the total amount of residue is usually less.

Crop Residues and Tillage Practices

Mannering and Fenster (1977) believe that the influence of tillage practices on placement of crop residues can have major effects on soil losses from erosion. They reported that the surface microtopography and plow-layer porosity of the soil following tillage can strongly affect soil erosion, but that residue placement is usually the dominant factor affecting the erosion process.

Mannering and Fenster (1977) grouped tillage instruments commonly used for a wide range of residue placement into several major categories that included moldboard plows; chisel plows and offset disks; field cultivators and shallow disks; and sweep or blade type implements. Moldboard plows leave little residue on the surface. Most of the residue is buried to a depth of 12 to 25 cm. Chisel plows and offset disks can leave appreciable amounts of residue on the surface, but partially incorporate some of the residues. These implements are also normally used at depths of 12 to 25 cm. Field cultivators and shallow disks leave appreciable amounts of residues on the surface and partially incorporate residues to a depth of 7 to 15 cm. Sweep or blade type implements can be used to undercut residues at shallow depths of 7 to 12 cm, while most of the residues are left on the soil surface.

Literature Review Summmary

This literature survey has revealed that the erosion process is complex, but that much progress toward erosion prediction and control has been made through emphasis on a few of the major factors influencing erosion. Application of the USLE has been an example of how knowledge of a few factors can result in improved erosion control practices. There has been general agreement among researchers that the erosion process begins when raindrops strike the soil surface; that the erosion process can be divided into rill and interrill components; that many soils when unprotected by cover exhibit a tendency to have a sealing effect, which results in reduced infiltration and increased runoff amounts; and that plant canopy and surface residues are highly beneficial in reducing erosion.

Researchers have been highly successful in using simulated rainfall on plots in field areas to study the various factors that influence erosion. Such studies have resulted in new information at a much more rapid pace than would be possible with just accumulation of data from field plots and watersheds under natural rainfall. Laboratory experiments that utilize rainfall simulator and small soil pans have also provided useful data, obtained under controlled conditions, for studying the basic mechanics of the erosion process.

The survey of literature shows that much has been learned about the role of crop residues, particularly those which are left on the surface, in reducing erosion. Limited information is available about the effectiveness of incorporated residues. Research reports on incorporated residue studies have been generally somewhat vague concerning the meaning of incorporation. Precise measurements of incorporated rates and depths were not generally given. The effect of variations in the ratios of surface to incorporated rates of residues has not been adequately studied. Future research that properly addresses the issue of incorporated residues will hopefully result in additional management alternatives that will be effective in reducing erosion.

PROCEDURE

Soil Description

The Grenada silt loam soil (Glossic Fragiudalf), was obtained from the North Mississippi Branch of the Mississippi Agricultural and Forestry Experiment Station, Holly Springs, Mississippi. The soil was removed from the plow layer (0-15 cm) in the summer of 1984 after being disked twice. It was sieved through a 12.7 mm mesh screen and allowed to air dry to a moisture content of about 1.5%.

Grenada silt loam is typical of highly erodible soils in the Mid-South, particularly loess over Coastal Plain material in the Southern Valley Silty Uplands land resource area. These soils have high silt and low sand content and are moderately to relatively high in fertility. The Grenada soils usually occur east of the Mississippi River and extend in a belt adjacent to Mississippi River bottomlands from Louisiana northward to the Ohio River (Virginia Agricultural Experiment Station, 1959). The soils are moderately well drained, but contain a fragipan at about 60 to 75 cm below the soil surface.

The area from which the soil was taken had been cropped in continuous corn. The soil contained about 4, 81, and 15% sand, silt and clay, respectively. The bulk density of the soil in place after the corn harvest of 1983 was 1.2 g/cm^3. Other properties of the soil included a cation exchange capacity of 7.3 me/100 g, a pH of 6.5, and a water holding capacity of about 16%. The percent moisture content at 0.33 and 15 bars of tension was 25.2 and 8.9%, respectively.

Exchangeable cations present in the soil included 6.41, 0.64, 0.02 and 0.24 me/100 gm of Ca, Mg, Na, and K, respectively.

Rainfall Simulator

A rainfall application rate of 64 mm/h has been widely used in rainfall simulator studies throughout the country. Thus a primary reason for selecting this application rate for this study was to ensure meaningful comparison with other studies.

Simulated rainfall at 64 mm/h was applied in a series of runs for each treatment in each of the three parts of this study. A soil pan was placed under simulated rainfall for an initial 60-minute run followed in 24 hours by two 30-minute runs separated by a 30-minute interval without rainfall. The initial, second, and third runs were designated dry, wet and very wet runs. The rainfall simulator was the same as described by Meyer and Harmon (1979).

A Veejet nozzle (size no. 80150) was located 3-m above the soil surface of test plots. The nozzle oscillated in an arc of about 90 degrees across the plot, not from one end of the slope of the plot to the other but from one side to the other. Each pass across the plot required about 0.5 seconds. A clutch-brake delayed the nozzle after each pass across the plot. The delay time was set by an electronic timer, which was designed to make provision for a wide range of application intensities. The delay time for an application rate of 64 mm/hr and a nozzle pressure of 41 N/m^2 was about 0.7 seconds. Meyer and Harmon (1979) reported that the impact energy of simulated raindrops from the 80150 nozzle with a pressure of 41 N/m^2 and a 3-m height provides an energy of 275 KJ/ha-mm. This energy is about the same as that computed for north Mississippi rainfall for intensities greater than 25 mm/h (McGregor and Mutchler, 1977).

Soil Pan Description

A Grenada silt loam soil was placed in a soil pan preceding each series of runs. The 0.91 by 0.91-m soil pan was constructed of plexiglass and the test plot consisted of a central 0.46 by 0.46 m area surrounded from border areas by plexiglass sides. Differences in splash into and out of the test area was considered negligible because of the border areas around the test plot, and because dimensions were about the same as used in standard soil pans reported in the literature by other researchers.

A slope of 2.5% was used in this study. This slope is well within the range of slopes used in other rainfall simulator studies and is representative of slopes on large areas of row cropped land. High rates of erosion have been measured even for relatively flat land. Murphree and Mutchler (1981) reported a 5-year average annual sediment yield of 17.7 t/ha for a Mississippi Delta watershed with a slope of only 0.2%.

Runoff was collected from a 1.3 cm wide slot at the lower end of the test area. Before each run a cover was placed over the slot that prevented rainfall from falling into the slot but still allowed runoff to flow into it.

An adjustable endplate was located at the lower end of the test area and initially placed such that the top of the endplate was within 1.3 cm of the top of the plexiglass sides and flush with the soil surface at the lower end of the test area. A similar endplate was also located at the lower end of the soil pan. Lowering of the endplates prevented the buildup of water due to slight settlement of the soil. Endplates were lowered about 0.32 cm during dry runs and another 0.16 cm preceding wet runs. Endplates were lowered at about 14 to 20 minutes into dry runs for incorporated straw treatments and at about 30 to 45 minutes for surface straw treatments.

The floor of the soil pan, including border areas, consisted of 1 cm thick plexiglass material with a grid layout of 1 cm diameter holes spaced 4.1 cm apart. The holes allowed free drainage of water in those instances when the soil became saturated; however, the soil depth of 8.6 cm was sufficient that complete saturation only very rarely occurred. The floor of the pan was covered before each series of runs with medium weight muslin cloth and 0.14 mm mesh fine wire screen in consecutive layers of cloth, screen, cloth, cloth, screen and cloth.

Methodology

Soil was poured loosely into the soil pan to within about 1.3 cm of the top of the pan. Final leveling of the soil surface was done with thin aluminum strips. The bottom of the strips inside the soil pan was at the proper depth for leveling the soil when extensions on the strips were pressed down on the top of the sides of the pan.

Straw segments, cut to 2.5 cm lengths, were hand-dropped into the soil pan. Although nearly all straw segments were positioned horizontally, there was no predominant downslope or perpendicular to slope orientation of the straw. For surface straw treatments, the required amount of straw was placed on the surface after the soil was leveled. For incorporated straw treatments, the specified amount of straw was uniformly distributed from the bottom to within about 0.3 cm of the top of the soil surface. This was accomplished by leveling the soil and straw to within 1.6 cm of the top of the pan, adding more soil to cover the straw, and then re-leveling the soil surface to within 1.3 cm of the top of the soil pan.

Soil surface profile measurements were made with a point gage. Five different readings at equally spaced intervals across the test area were taken for each transect. There were six transects equally spaced up and down the plot. Profile readings were also taken after a series of runs for treatments with zero levels of surface straw.

Soil moisture samples were collected from the top 2.5 cm of soil in the border areas before and after runs. Estimates of bulk density were made by weighing the soil and straw placed into the soil pan preceding each series of runs. Bulk densities for treatments with 0, 1 through 5, and 6.7 through 9 t/ha of incorporated straw averaged 1.26, 1.20, and 1.15 g/cm^3 with standard deviations of 0.04, 0.06, and 0.08 g/cm^3, respectively.

The test area was covered with a 5 cm mesh wire screen before and after each series of runs, and photographs taken to provide visual records of surface cover. In addition, estimates of percent surface cover were made before and after each series of runs using transects containing a smaller grid network. Transects were taken at 8, 23 and 38 cm from the upper end of the test area. A 2.5 cm square area was divided into 0.64 cm square grids at four equally spaced locations within each transect. Percent ground cover was the average of all visual estimates that were made in the test plot.

Runoff during runs were collected in tared Kerr #505 regular mason glass jars. Each jar held all the runoff for a 4-minute interval, except for the last interval during the 30-minute runs, which was only two minutes. The amount of runoff and soil loss in each of the samples was measured to the nearest 0.01-g from tare weights, gross weights after runs, and net weights after water was removed by drying at 105 degrees celsius.

All recession runoff was collected during a 4-minute interval following each run. Some soil after each run remained in the 1-m long PVC pipe leading from the runoff slot at the lower end of the test area to the collection jars. This soil was washed into another jar, designated as a pipe clean-out sample, and added to the total soil loss for the run.

Provision was also made for the collection of any percolation water passing through the soil profile during runs and during a 4-minute interval following runs. But water infiltrating through the soil profile was negligible.

Statistical Designs Used in Study

The experiment was divided into three parts to test the effects of surface straw, incorporated straw, and combinations of surface and incorporated straw. An analysis of variance was made for each of the three parts of the experiment. The incorporated straw study was from Oct. 2 to Nov. 15, 1984; the surface straw study was from Dec. 19, 1984 to April 30, 1985; and the combined surface - incorporated study was from May 15 to June 26, 1985.

The effects of varying rates of surface straw on runoff and soil loss was determined by using a randomized block design. There were seven treatments (0, 0.5, 1, 2, 4, 6 and 8 t/ha of surface straw) with three replications of each treatment. A replication of each treatment was included in each of three blocks. The reason for blocking was to ensure that any effect caused by the length of time required to complete all tests would not cause any bias toward any particular treatment.

A completely randomized design was used to test the effects of incorporated straw on runoff and soil loss. There were five treatments (0, 2.2, 4.5, 6.7 and 9 t/ha of incorporated straw) with five replications at the 0 and 9 t/ha levels and two relications for each of the remaining levels of incorporated straw. Preliminary tests had indicated no effect of incorporated straw on soil loss, so more replications were chosen for the extreme levels, which would really be all that would be needed if results from preliminary tests were verified. Two replications of intermediate levels were included in the design just in case the preliminary results should prove to be misleading.

A 4x2 factorial experiment was used to test the effects of combinations of surface straw and incorporated straw on runoff and soil loss. Incorporated straw rates were 1, 3, 5 and 7 t/ha, while surface straw rates were 1 and 3 t/ha; thus, there were eight treatment combinations. A randomized block design was used in which each of the eight treatment combinations was included once in each of three blocks.

These rates of incorporated and surface straw combinations were chosen after preceding tests for the effects of incorporated straw alone and surface straw alone had already been conducted. A lower surface rate of straw than 1 t/ha would have resulted in a surface condition too much like a bare surface, for which incorporated rates had already been found to be insignificant. Selection of a surface rate much higher than 3 t/ha would result in satisfactory reduction of soil loss by the surface straw alone.

Randomized Block Design

Any runoff or soil loss observation in the randomized block design (RBD) used in the study of the effects of surface residues was assumed to be the summation of a general mean, a treatment effect, a block effect, and an experimental error. All of the experimental units were assumed to have been assigned into homogeneous groups, or blocks, and treatments were randomly assigned within each of the blocks. Treatment and block effects were assumed to be additive. For example, the difference between the true effects of two treatments was assumed to be the same within one block as in any other block. Experimental errors were assumed to be independent random variables distributed with a mean of zero and the same variance σ^2.

Computations for the sum of squares used in an analysis of variance (ANOVA) table for a RBD design in which treatments were replicated only one in each of the blocks were:

$$SST = \Sigma\ y_{ij}^2 - G^2/ij$$

$$SSTR = \Sigma\ (T_i^2/j) - G^2/ij$$

$$SSBL = \Sigma\ (B_j^2/i) - G^2/ij$$

$$SSE = SST - SSTR - SSBL$$

where SST, SSTR, SSBL and SSE were the adjusted total, treatment, block and error sum of squares, respectively; i and j were the number of treatments and blocks, respectively; y_{ij} was the observation for the i'th treatment and j'th block; G was the grand total of all observations; T_i was the total of all observations for treatment i across all blocks; and B_j was the total of all observations for block j across all treatments.

Treatment, block and error mean squares were equal to SSTR/(i-1), SSBL/(j-1) and SSE/(i-1)(j-1), respectively, where the denominators represented the respective degrees of freedom for treatments, blocks and errors. The F value used to test the significance of the effects of treatments was equal to the treatment mean square divided by the error mean square. Likewise, the F value used to test the significance of the effects of blocks was equal to the block mean square divided by the error mean square. Cochran and Cox (1957) and Snedecor and Cochran (1967) provided more detailed information concerning assumptions involved in RBD designs as well as for completely randomized designs and the factorial experiments.

Completely Randomized Design

Any runoff or soil loss observation in the completely randomized design (CRD) used in this study was assumed to be the summation of a general mean, a treatment effect and an experimental error. Experimental errors were assumed to be independent random variables distributed with a mean of zero and the same variance σ^2. There was no restriction on randomization, thus all of the variation among the experimental units were included in the experimental error.

For i treatments, r_i replications for the i'th treatment, n total number of observations, y_{ij} equal to the observation for the i'th treatment and j'th replication, G equal to the grand total of all observations, and T_i equal to the total of all observations for the i'th treatment, the sums of squares were computed as follows:

$$SST = \Sigma\ Y_{ij}^2 - G^2/n$$

$$SSTR = \Sigma\ (T_i^2/r_i) - G^2/n$$

SSE = SST - SSTR

where SST, SSTR and SSE were the adjusted total, treatment and error sums of squares, respectively. Treatment and error mean squares were equal to SSTR/(i-1) and SSE/(n-i), respectively, where the denominators represented the respective degrees of freedom for treatments and errors. The ratio of the treatment mean square and error mean square was the F value that was used to test the significance of treatment effects.

Factorial Experiment

In the factorial experiment in a RBD design used in this study, there were four levels of one factor, incorporated straw, and two levels of a second factor, surface straw. Any runoff or soil loss observation in this experiment was assumed to be the summation of a general mean, a main effect of incorporated straw, a main effect of surface straw, a possible two-factor interaction effect and an experimental error. Errors were assumed to be independent random variables distributed with a mean of zero and the same variance σ^2. Cochran and Cox (1957) presented an example of a 4 x 2 factorial in which calculations for entries into an ANOVA table are illustrated. They also gave detailed information on several other factorial experiments.

RESULTS

Effects of Various Rates of Surface Straw on Runoff

In this randomized block experiment, treatments consisted of seven rates of surface straw application, ranging from 0 to 8 t/ha. Table 3 shows runoff and the rate of surface straw for each treatment within each of three blocks. Each runoff value is the total from dry, wet and very wet runs. Runoff slightly increased with increasing rates of straw up to 2 t/ha and then only slightly decreased with further additions of straw.

An analysis of variance, Table 4, shows no significant blocking effect. Thus, allowances made for possible blocking effects caused by time delays between different sets of runs were not necessary. Application of different rates of surface straw did have a significant statistical effect on runoff, although the F value for significance was not nearly as pronounced as that for the effect of rates of surface straw on soil loss.

The product of the one-tailed t value (12 degrees of freedom, 5% level) of 1.782 and a standard error of estimate for the difference between two means of 0.25 gave an LSD of 0.45 cm. Thus, the average runoff of 7.86 cm for the 2 t/ha rate of surface straw was significantly greater than the mean runoff for each of the other surface straw rates except that for 1 t/ha.

Table 3. Sum of runoff from dry, wet and very wet runs for different rates of surface straw.

Treatment	Runoff				
Surface Straw[a] (t/ha)	Block 1 (cm)	Block 2 (cm)	Block 3 (cm)	Average (cm)	Total (cm)
0	6.28	7.00	6.62	6.63	19.90
0.5	7.06	7.30	7.41	7.26	21.77
1	7.97	7.57	7.14	7.56	22.68
2	7.93	7.70	7.95	7.86	23.58
4	7.59	7.18	7.16	7.31	21.93
6	7.03	6.79	6.72	6.85	20.54
8	6.63	6.02	6.74	6.46	19.39
Total	50.49	49.56	49.74		149.79

a/ Ground cover averaged 20, 41, 71, 95, 100 and 100% for the 0.5, 1, 2, 4, 6 and 8 t/ha surface straw rates, respectively.

Table 4. Analysis of variance for runoff (cm) from dry + wet + very wet runs for different rates of surface straw (t/ha).

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	20	5.7910			
Straw	6	4.6127	0.7688	8.32	3.00
Blocks	2	0.0695	0.0348	0.38	3.88
Error	12	1.1088	0.0924		

Use of a two-tailed t value (12 degrees of freedom, 5% level) gives an LSD of 0.54 cm for testing whether pairs of means are different, as opposed to testing whether one is greater than the other. Use of this more conservative test results in runoff for the 2 t/ha rate of surface straw also being statistically different from runoff from every other rate except for that at 1 t/ha. Use of this t value also shows that runoff for an application rate of 0 t/ha was significantly different from every mean runoff value except that at 6 t/ha and that at 8 t/ha.

An exponential relationship was derived for runoff as a function of surface straw for the interval from 2 to 8 t/ha. Using this equation, runoff was predicted for surface straw rates at 0, 0.5 and 1 t/ha. Residual values for these points (observed minus predicted) were in turn described by another exponential relationship. Combining the two exponential relationships and entering initial parameter estimates into a model parameter optimization program resulted in the following relationship:

$$R.O. = 8.42\ e^{-0.033(ST)} - 1.82\ e^{-1.228(ST)},\quad r^2 = 0.77$$

where runoff (R.O.) is in cm and surface straw (ST) is in t/ha.

This equation allows values of runoff to continue to decrease with increases in surface straw in the higher ranges. The equation is presented graphically in Figure 1. Runoff increases with surface straw rates up to about 2 t/ha and then decreases for further additions of surface straw.

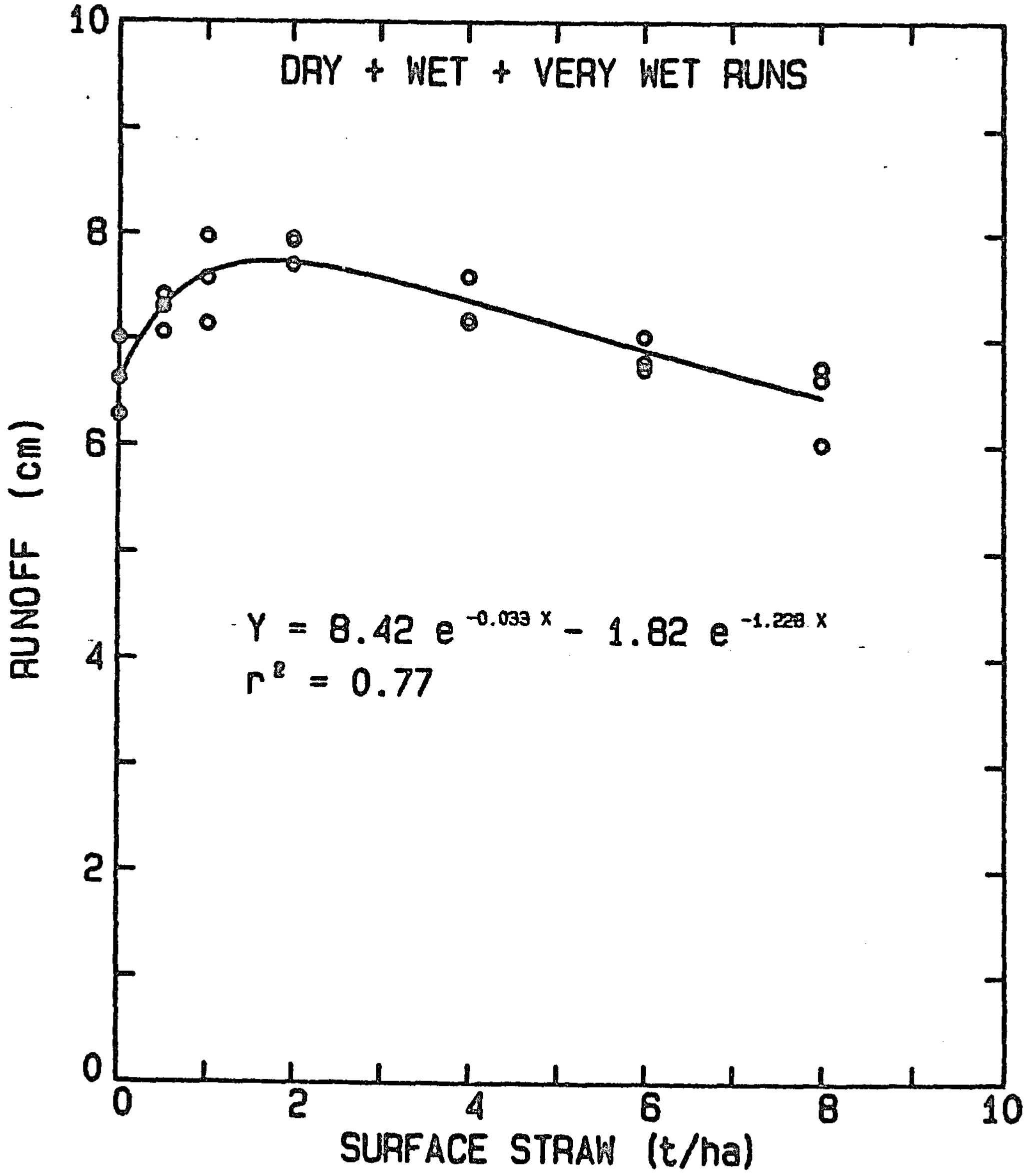

Figure 1. The relationship between runoff (cm) and surface straw (t/ha) for the sum of dry, wet and very wet runs

Runoff from Dry, Wet and Very Wet Runs

Tables 5, 6, and 7 give the runoff values from each type of run for the various rates of surface straw. Table 8 gives the analysis of variance for each type of run. Treatments, or rates of surface straw, were significant in each type of run, but the effects of blocking according to time were not significant for any type of run.

The following equation expresses a linear relationship between runoff and surface straw for the dry runs:

$$RO = 2.54 - 0.09\ ST,\quad r^2 = 0.77$$

where runoff (RO) is in cm and surface straw (ST) is in t/ha.

The following equations express the relationship between runoff and surface straw for the wet and very wet runs;

Wet: $$R.O. = 2.77\ e^{-0.021(ST)} - 0.82\ e^{-1.277(ST)},\quad r^2 = 0.81$$

Very Wet: $$R.O. = 2.83\ e^{-0.022(ST)} - 0.53\ e^{-1.103(ST)},\quad r^2 = 0.74$$

where runoff (R.O.) is in cm and surface straw (ST) is in t/ha. The derivation procedure was the same as described earlier for the sum of runoff from dry, wet and very wet runs as a function of surface straw rates. The linear relationships for the dry runs and the exponential summation relationships for the wet and very wet runs are presented graphically in Figures 2, 3 and 4, respectively.

Table 5. Runoff from dry runs for different rates of surface straw.

Treatment	Runoff				
Surface Straw (t/ha)	Block 1 (cm)	Block 2 (cm)	Block 3 (cm)	Average (cm)	Total (cm)
0	2.24	2.47	2.34	2.35	7.05
0.5	2.28	2.41	2.69	2.46	7.38
1	2.86	2.52	2.29	2.56	7.67
2	2.50	2.32	2.59	2.47	7.41
4	2.46	2.06	2.20	2.24	6.72
6	2.05	1.83	1.86	1.91	5.74
8	1.82	1.62	1.83	1.76	5.27
Total	16.21	5.23	15.80		47.24

Table 6. Runoff from wet runs for different rates of surface straw.

Treatment	Runoff				
Surface Straw (t/ha)	Block 1 (cm)	Block 2 (cm)	Block 3 (cm)	Average (cm)	Total (cm)
0	1.74	2.13	2.04	1.97	5.91
0.5	2.21	2.38	2.25	2.28	6.84
1	2.46	2.53	2.39	2.46	7.38
2	2.69	2.66	2.66	2.67	8.01
4	2.52	2.51	2.44	2.49	7.47
6	2.45	2.47	2.42	2.45	7.34
8	2.43	2.15	2.40	2.33	6.98
Total	16.50	16.83	16.60		49.93

Table 7. Runoff from very wet runs for different rates of surface straw.

Treatment	Runoff				
Surface Straw (t/ha)	Block 1 (cm)	Block 2 (cm)	Block 3 (cm)	Average (cm)	Total (cm)
0	2.30	2.40	2.24	2.31	6.94
0.5	2.57	2.51	2.47	2.52	7.55
1	2.65	2.52	2.46	2.54	7.63
2	2.74	2.72	2.70	2.72	8.16
4	2.61	2.61	2.52	2.58	7.74
6	2.53	2.49	2.44	2.49	7.46
8	2.38	2.25	2.51	2.38	7.14
Total	17.78	17.50	17.34		52.62

Table 8. Analysis of variance for runoff (cm) from dry, wet and very wet runs for different rates of surface straw (t/ha).

DRY RUNS

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	20	2.1157			
Straw	6	1.6601	0.2767	8.59	3.00
Blocks	2	0.0692	0.0347	1.08	3.88
Error	12	0.3864	0.0322		

WET RUNS

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	20	1.0258	0.0513		
Straw	6	0.8639	0.1440	11.25	3.00
Blocks	2	0.0082	0.0041	0.32	3.88
Error	12	0.1537	0.0128		

VERY WET RUNS

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	20	0.3995			
Straw	6	0.3184	0.0531	9.48	3.00
Blocks	2	0.0142	0.0071	1.27	3.88
Error	12	0.0669	0.0056		

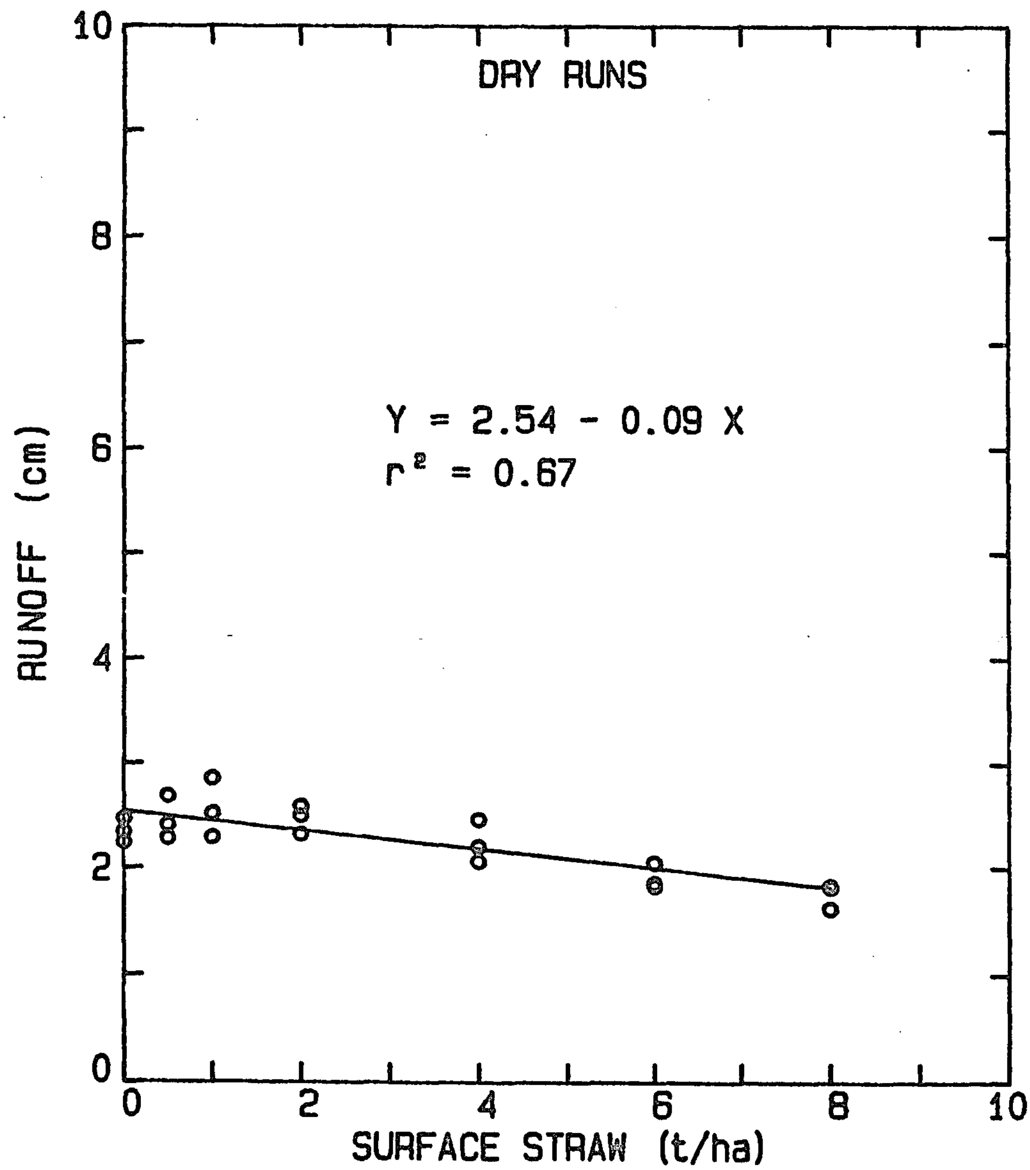

Figure 2. The relationship between runoff (cm) and surface straw (t/ha) for dry runs.

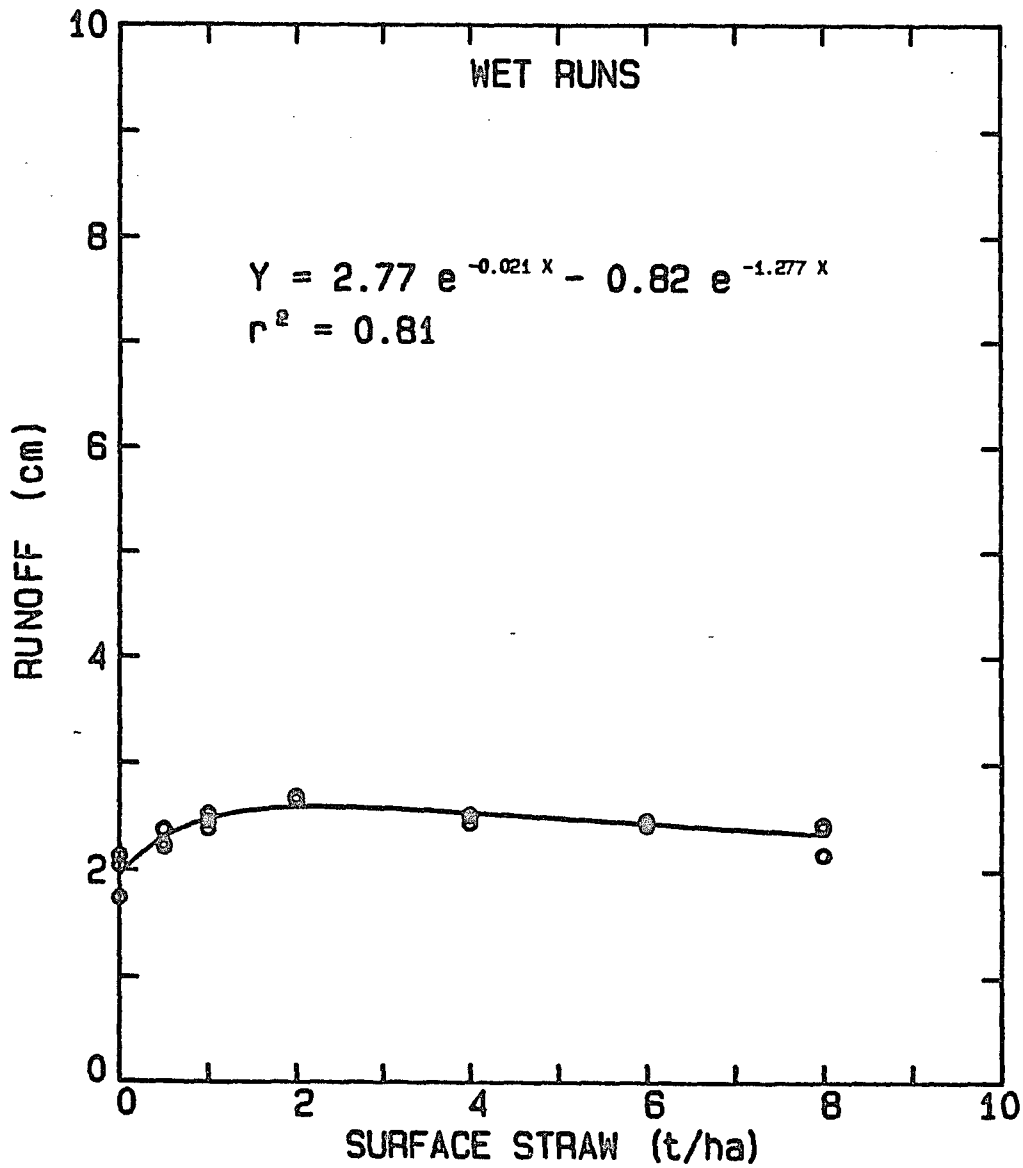

Figure 3. The relationship between runoff (cm) and surface straw (t/ha) for wet runs.

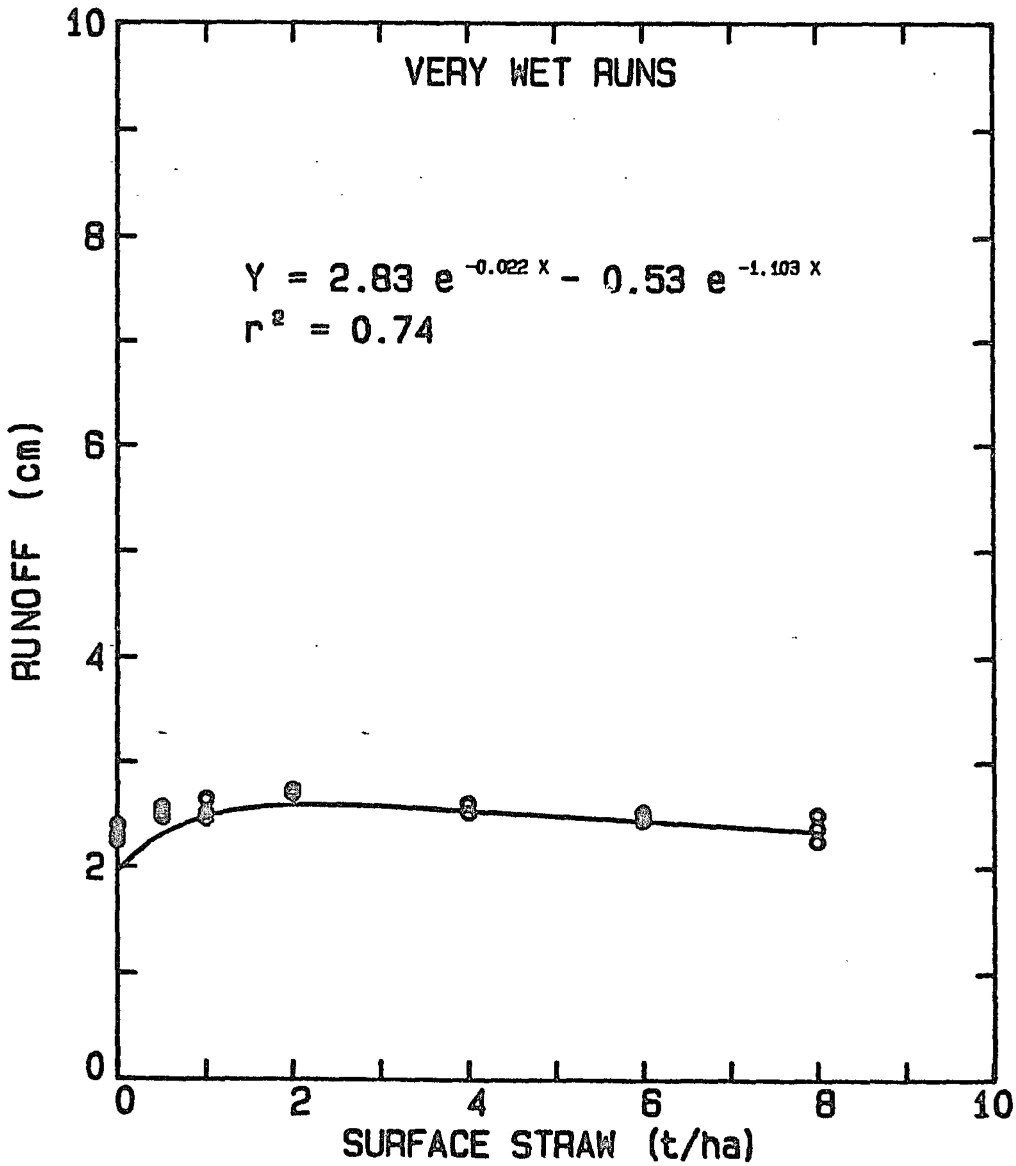

Figure 4. The relationship between runoff (cm) and surface straw (t/ha) for very wet runs.

Table 9 shows an analysis of variance for which runoff values were subdivided into two types of runs; a 60-minute dry run and a 60-minute period using the sum of the wet and very wet runs. Rates of surface straw were significant. The sum of runoff from the wet and very wet runs was significantly greater than that from dry runs. Interaction between surface straw rates and type of run was also significant. The following equation was derived to express the relationship between runoff and surface straw for the wet plus very wet runs:

$$R.O. = 5.60\ e^{-0.022(ST)} - 1.29\ e^{-1.040(ST)},\quad r^2 = 0.83$$

with runoff (R.O.) in cm and surface straw (ST) in t/ha.

Figure 5 shows a graphical comparison of runoff from dry runs with that from wet plus very wet runs. The linear regression for dry runs shows decreasing runoff amounts for increasing surface straw rates. Differences between the two types of runs are increasing from 0 to 2 t/ha because runoff within this range is increasing for the wet plus very wet runs.

Straw segments on the soil surface were spread in a random pattern so that straw lengths were not arranged in any particular direction. The spray pattern from the nozzle applying rainfall was such that rainfall hit the surface in a sweeping motion from one side to the other side of the test area. This pattern resulted in a sideward force being applied to the uppermost straw segments, except when the nozzle was directly overhead once during each pass. Low rates of surface straw allowed all straw segments to be exposed to raindrop action. At

Table 9. Analysis of variance for runoff (cm) for seven rates of surface straw (0 to 8 t/ha) for 60-minute dry runs and the sum of wet and very wet runs.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	41	77.4224			
Straw	6	2.3064	0.3844	13.64	2.44
Type of Run (Dry vs. Sum of Wet + Very Wet)	1	72.8380	72.8380	2582.91	4.20
Interaction	6	1.4782	0.2464	8.74	2.44
Error	28	0.7909	0.0282		

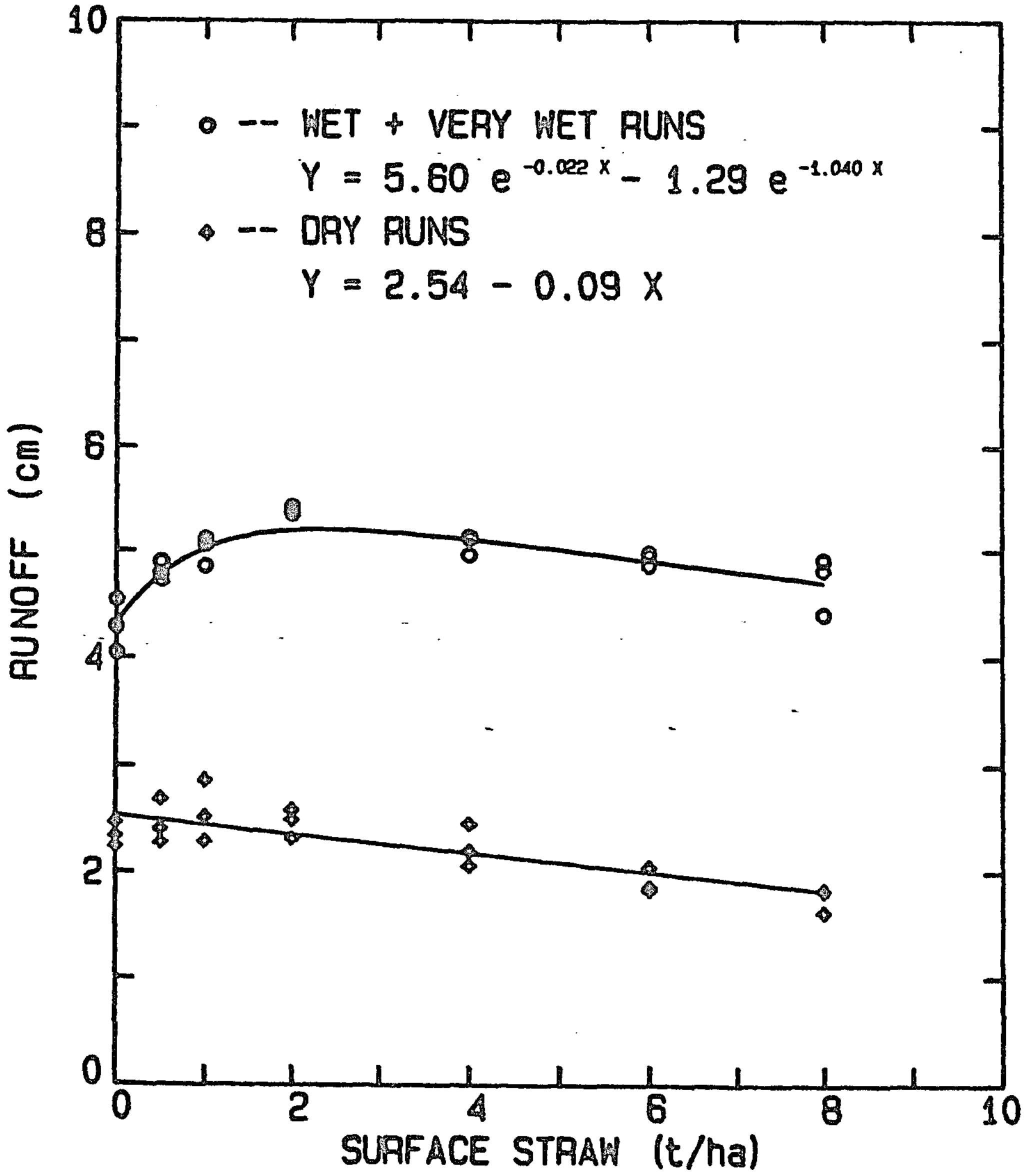

Figure 5. Comparison of equations relating runoff (cm) and surface straw (t/ha) for a 60-minute initial dry run and for the sum of two 30-minute (wet + very wet) runs.

the end of very wet runs, these straw segments were predominately arranged in a downward slope, or parallel to slope direction. A major re-orientation of straw segments began in the dry runs and continued into the very wet runs for rates of straw less than 1 t/ha. The increasing orientation of straw segments toward a parallel slope direction, as time increased during each run, tended to streamline or channelize the flow more toward the outlet at the lower end of the test area. This phenomena explains why runoff in the wet and very wet runs increased for increasing rates of surface straw in the lower ranges.

More runoff was expected from a bare surface, particularly because of observed development of surface seal on the unprotected soil. However, addition of surface straw at low rates, such that major areas of soil remained exposed to surface sealing effects while straw segment orientation effects occurred as described above, led to increased runoff. When enough straw was added, surface sealing was reduced. Furthermore, there were many more straw segments to re-orient. With enough straw added so that most segments were beneath other segments, it became more difficult for a majority of the segments to be re-oriented. Rather than channelizing flow, higher rates of surface straw tended to retard flow by increasing travel distance of runoff.

Why runoff with higher rates of surface straw (2 t/ha and beyond), although decreasing with additional increases of straw, still was higher in the wet and very wet runs than with zero levels of straw is difficult to understand. It may be that a boundary layer formed at the surface layer, which although less developed than that for bare soil, was still sufficient for lateral flow of runoff. This lateral flow might have been enhanced by the build-up of water held within the surface straw layer. Runoff from dry runs for 8 t/ha surface straw rates was about 0.6 cm or 25% less than from that for 0 t/ha surface straw rates. Runoff rates during the dry runs for the 0 t/ha straw rates began earlier and were higher than those for the 8 t/ha rates until about 40 minutes into the runs. Thereafter, runoff rates from the bare surface was less than from the covered surface. Final runoff rates at the end of dry runs were about 0.06 and .075 cm/min for the 0 and 8 t/ha surface straw rates, respectively. Runoff rates during the wet and very wet runs continued to be higher for the surface straw plots than for the bare surface plots. Total runoff, then, from the covered plots was also greater for the wet and very wet runs.

Figures 6 through 12 show average runoff rates during dry, wet and very wet runs for each of the seven rates of surface straw (0 to 8 t/ha) used in this study. These figures show that runoff was initiated earlier in the dry runs for 0 t/ha than with higher surface straw rates; however, runoff rates at the end of dry runs and throughout wet and very wet runs were less than from plots with applications of surface straw.

Although regressions relating total runoff with surface straw rates provided statistically significant fits to the data for each type of run, visual inspections of plotted data do not reveal much change in runoff for most of the different rates of surface straw. In addition, the LSD tests show that many of the differences between mean values

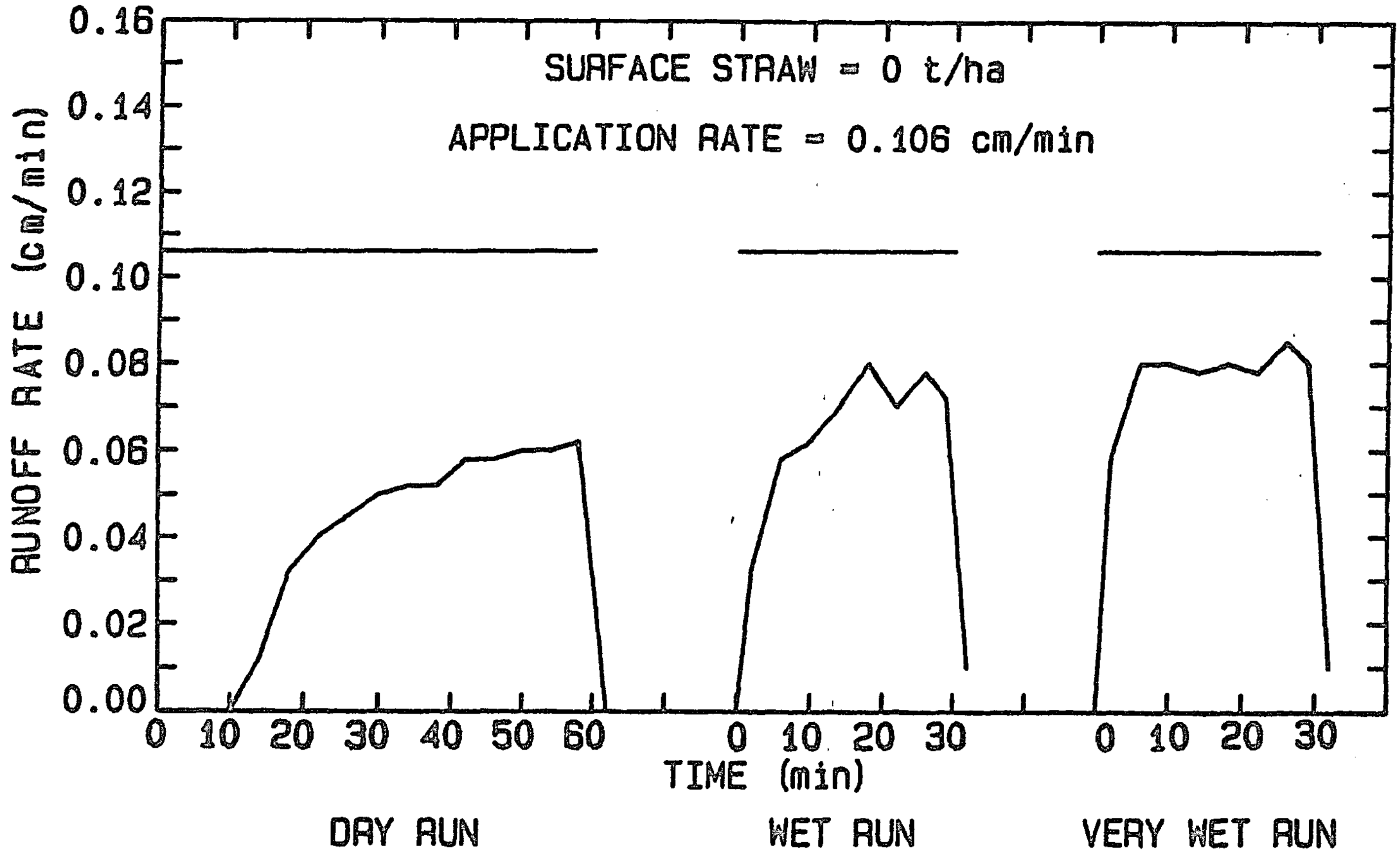

Figure 6. Runoff rate (cm/min) versus time during dry, wet and very wet runs for a surface straw rate of zero t/ha.

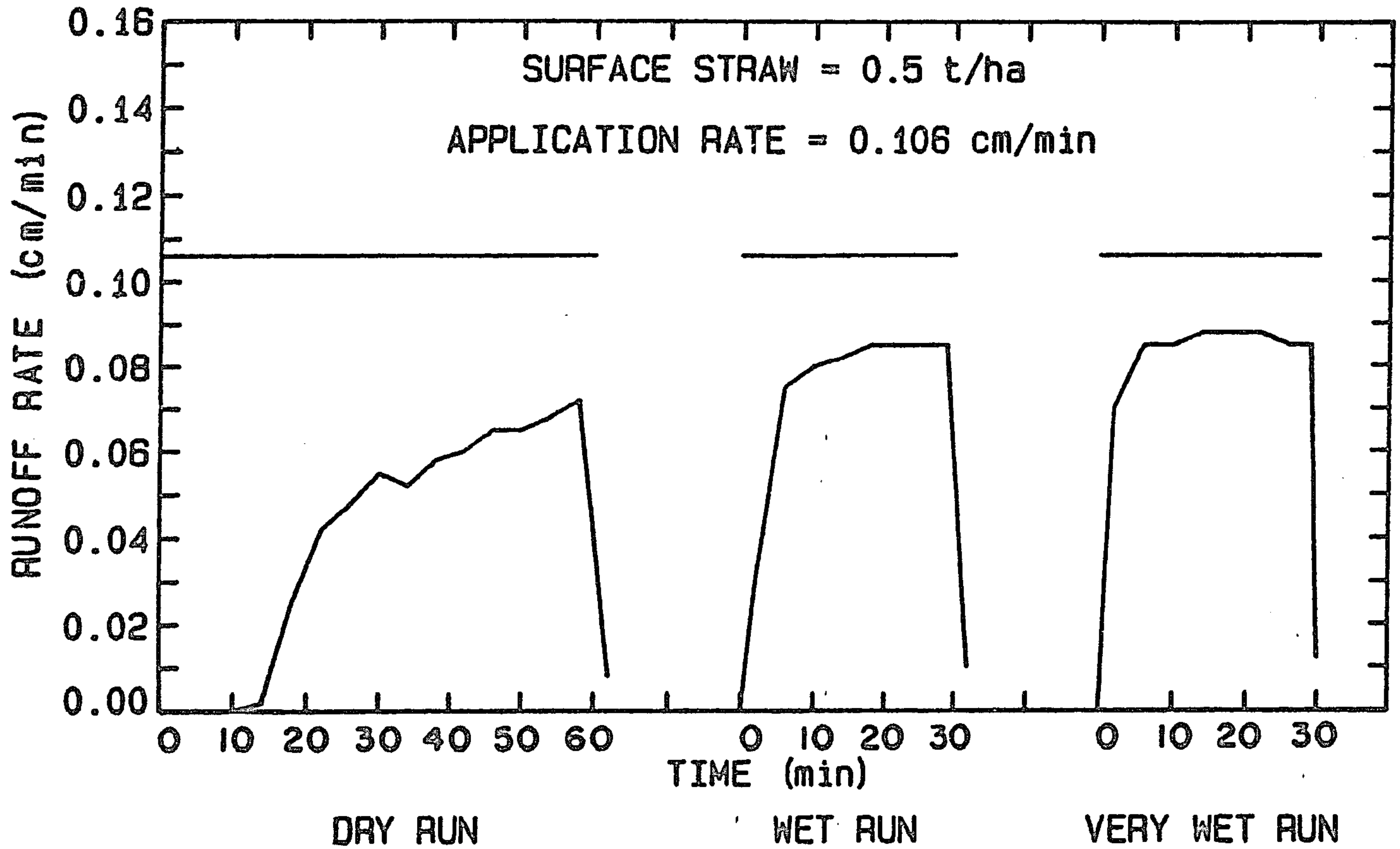

Figure 7. Runoff rate (cm/min) versus time during dry, wet and very wet runs for a surface straw rate of 0.5 t/ha.

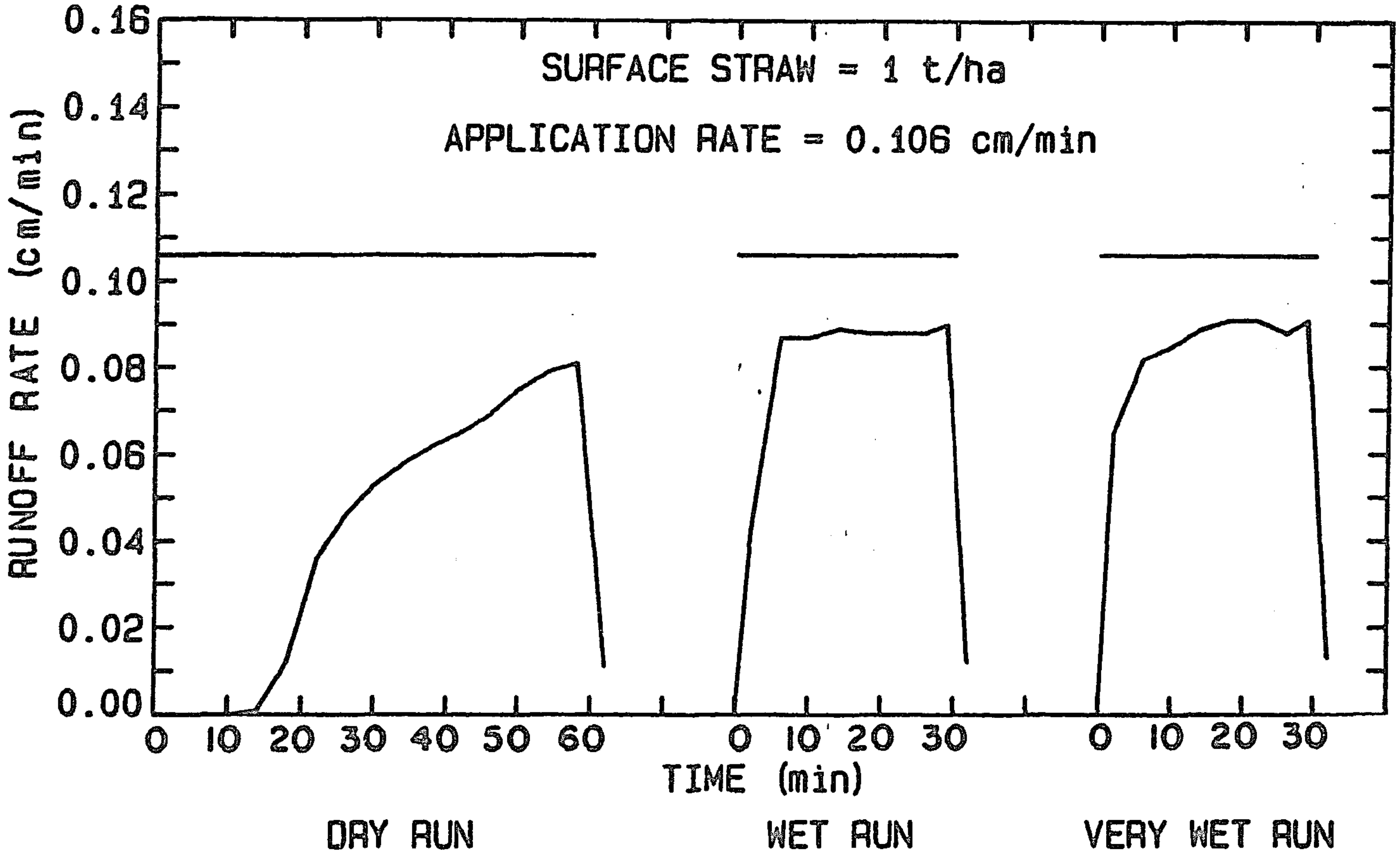

Figure 8. Runoff rate (cm/min) versus time during dry, wet and very wet runs for a surface straw rate of 1.0 t/ha.

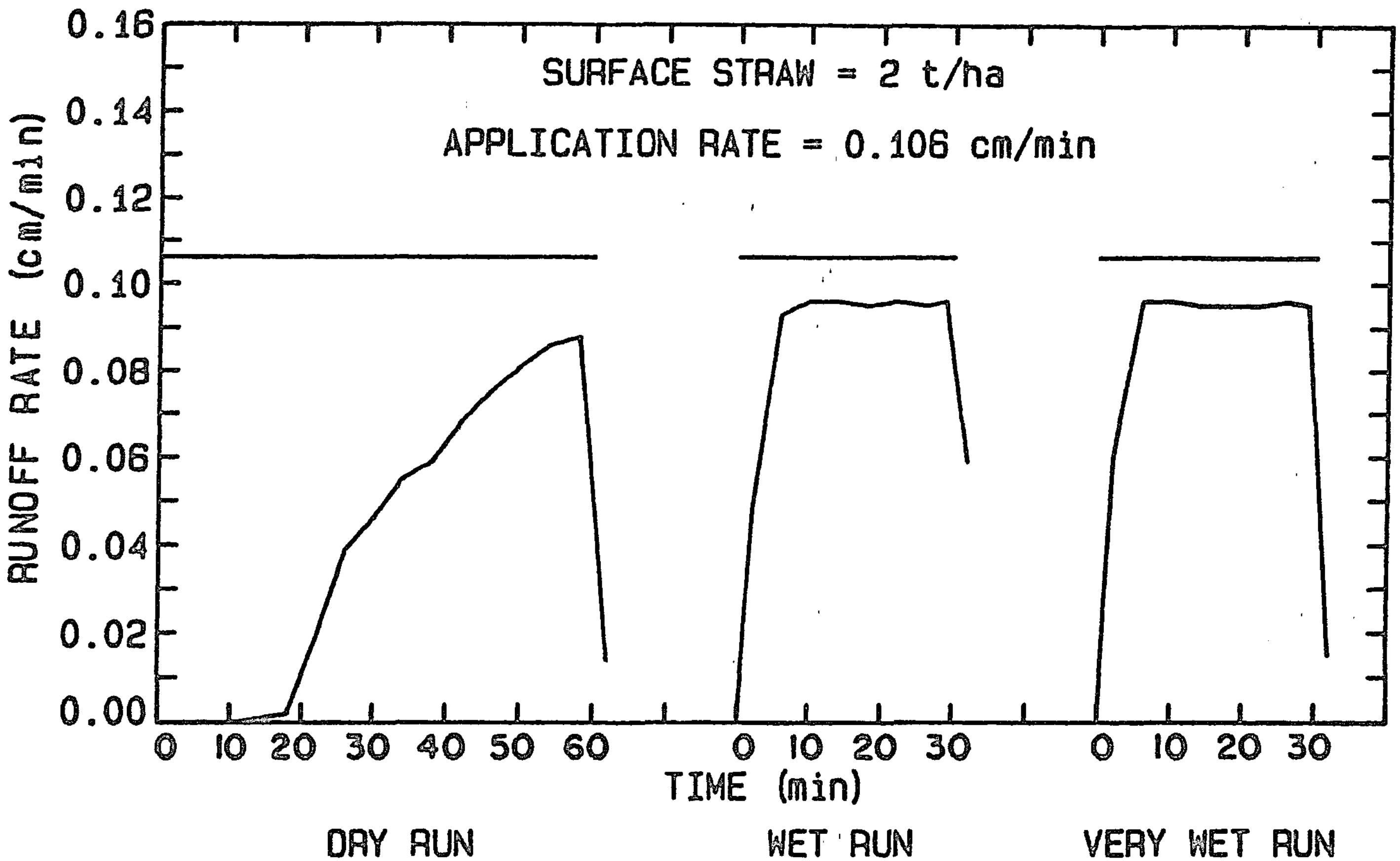

Figure 9. Runoff rate (cm/min) versus time during dry, wet and very wet runs for a surface straw rate of 2 t/ha.

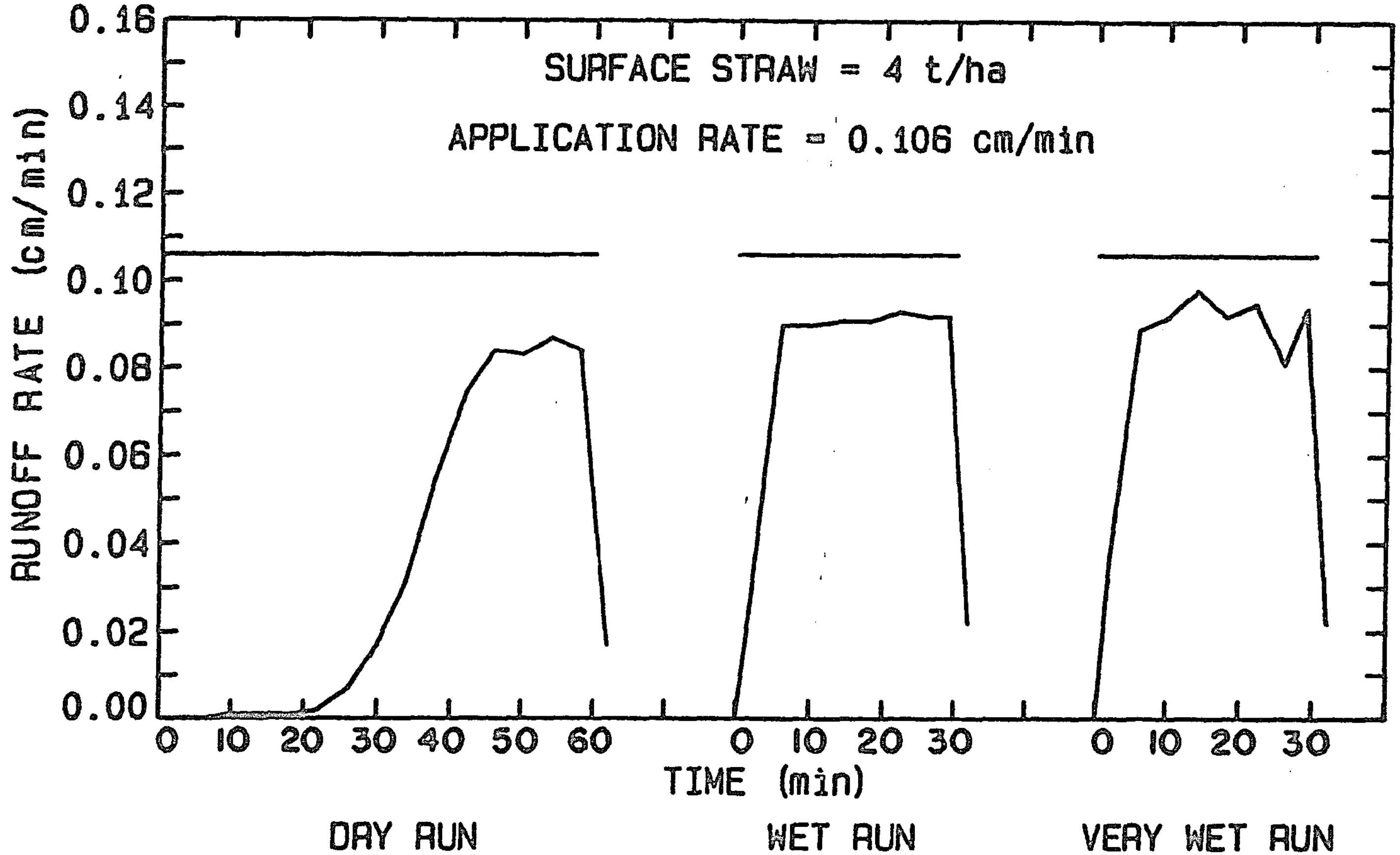

Figure 10. Runoff rate (cm/min) versus time during dry, wet and very wet runs for a surface straw rate of 4 t/ha.

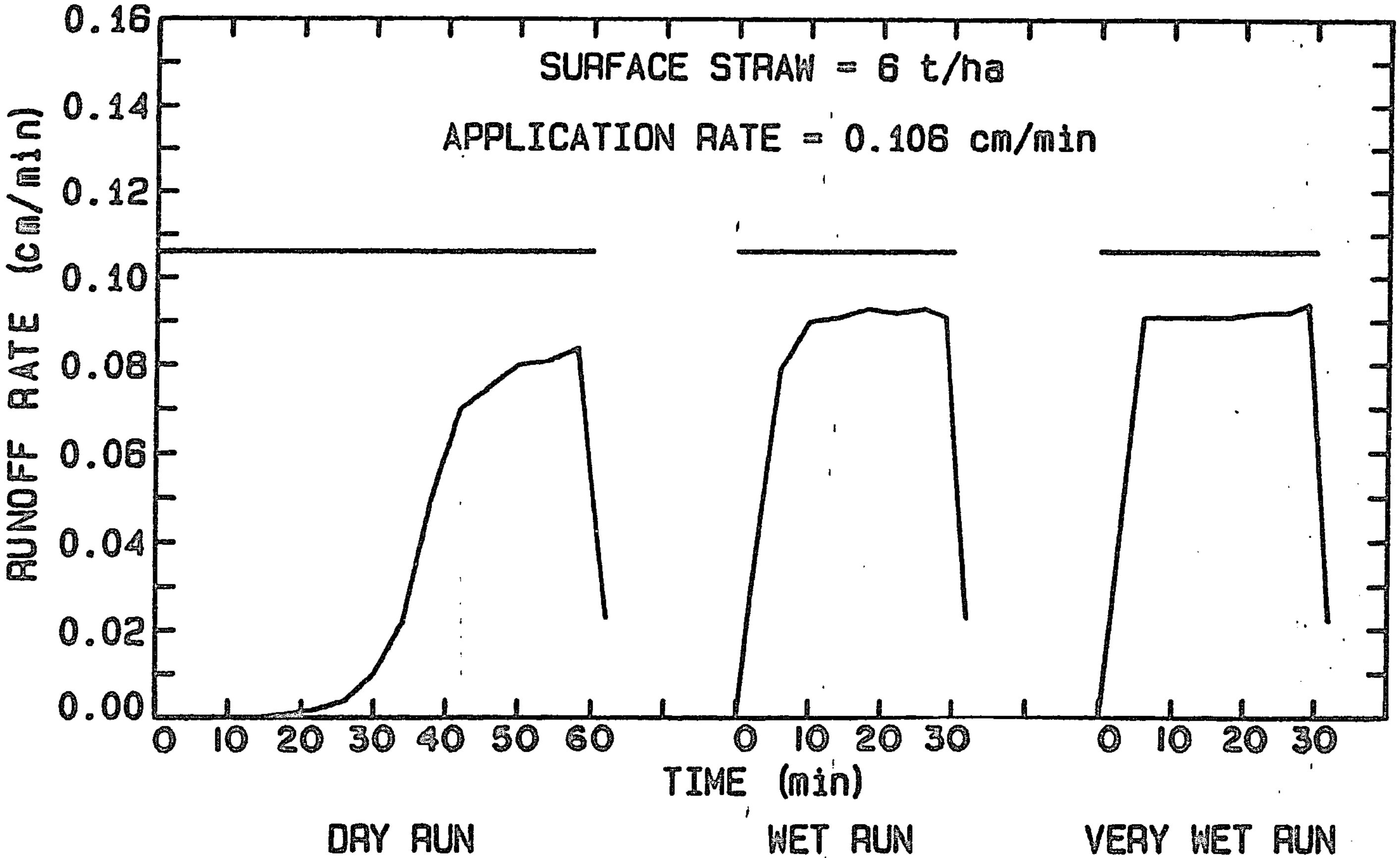

Figure 11. Runoff rate (cm/min) versus time during dry, wet and very wet runs for a surface straw rate of 6 t/ha.

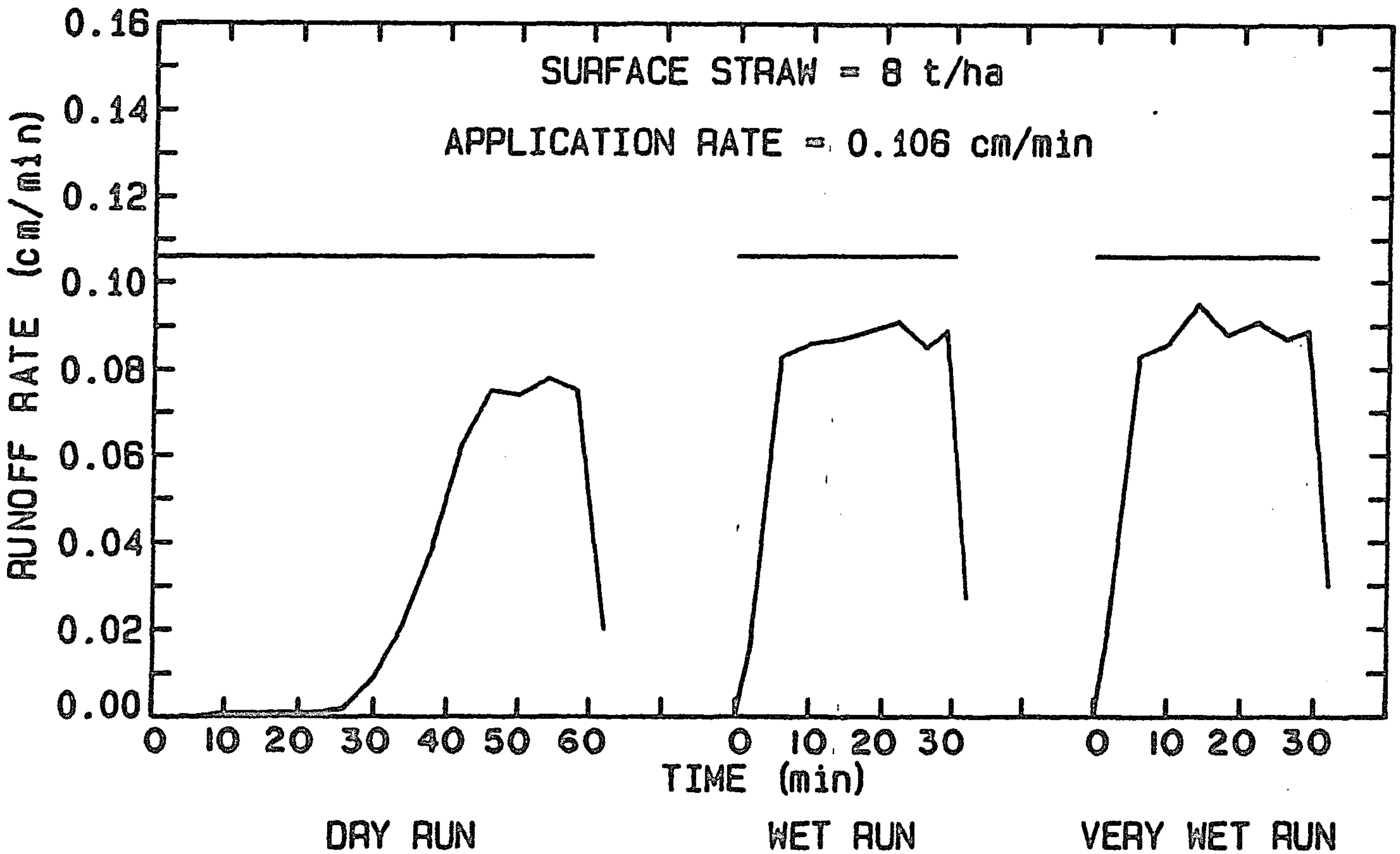

Figure 12. Runoff rate (cm/min) versus time during dry, wet and very wet runs for a surface straw rate of 8 t/ha.

were not significant. For example, in the wet runs none of the pairs of means for 1, 4, 6 and 8 t/ha were significantly different. In the very wet runs, none of the pairs of means for 0.5, 1, 4 and 6 t/ha were significantly different, nor was runoff for the 6 t/ha surface straw rates significantly different from that at 8 t/ha. LSD values were very low, being 0.27, 0.16 and 0.11 cm for dry, wet and very wet runs, respectively. From a practical viewpoint, regardless of statistically significant regressions, the small differences in runoff for different rates of surface straw could not account for appreciable differences in soil losses.

If lower than expected values for near zero rates of surface straw, as compared to other rates of straw, were real and not the result of random experimental error, a possible error in experimental design could have caused such results. The assumption had been made that splash out of the test area was equal to splash back into the test area from the surrounding border area. This may have been a false assumption. There may have been more splash out than back into the test area for rates less than about 1 to 2 t/ha. Surface straw above this rate caused droplets to splash in a more vertical direction, thus minimizing any difference in splash out and back into the test area. Thus the assumption could still hold for the higher rates even if not valid for rates of surface straw near zero.

Some tests were made in which the border area was extended around the test plot. Results were inconclusive as to whether there were any differences with use of the extended border. In order to adequately test the effects of an extended border, more applicator nozzles would need to be used, for the intensity distribution of the raindrops decreases with distance away from the upper and lower ends of the test area. This test will be made as a follow-up to this study.

Effects of Various Rates of Surface Straw on Soil Loss

In this randomized block experiment, treatments consisted of seven rates of surface straw applications, ranging from 0 to 8 t/ha. Table 10 shows the rate of surface straw and the soil loss from each treatment within each block. Each soil loss value is the total of dry, wet and very wet runs. The maximum average soil loss for the three blocks occurred for the second treatment (0.5 t/ha) followed next by the first treatment (0 t/ha). Soil losses for the third through seventh treatments decreased for additional increases in surface straw applications.

An analysis of variance (Table 11) shows that treatments were significant at the 5 percent level; whereas, blocks were not significant. The general trend for treatments was that soil loss decreased with increasing rates of surface straw applications.

The least significant difference (LSD) method was used to test comparisons between pairs of mean values of soil loss for the various rates of surface straw applications. The 5% value of t (one-tailed test) with 12 degrees of freedom (d.f.) is 1.782. The standard error of the difference between two means is equal to 43.24, thus the LSD is equal to (1.782)(43.24) = 77. A one-tailed t value provides a test of

Table 10. Sum of soil losses from dry, wet and very wet runs for different rates of surface straw.

Treatment Surface Straw (t/ha)	Soil Losses Block 1 (g/m^2)	Block 2 (g/m^2)	Block 3 (g/m^2)	Average (g/m^2)
0	658	659	734	684
0.5	792	757	593	714
1	588	592	601	594
2	576	546	463	528
4	253	219	121	198
6	181	144	88	138
8	52	90	76	73

Table 11. Analysis of variance for the soil losses (g/m^2) from dry + wet + very wet runs for different rates of surface straw (t/ha).

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	20	1390680			
Straw	6	1342846	223808	80	3.00
Blocks	2	14190	7095	2.53	3.88
Error	12	33644	2804		

whether one mean is significantly greater than another. The one-tailed value is used here because an increase in protective cover on the surface should result in a decrease in erosion rates.

A rate of 0 t/ha of surface straw was found to be significantly greater than that for 1 t/ha, 0.5 greater than 1, 2 greater than 4, and 6 greater than 8 t/ha. Pairs of means for which a significant difference did not occur included 0 versus 0.5, 1 versus 2, and 4 versus 6 t/ha.

Just because a difference in soil loss for some adjacent treatments was not statistically significant does not mean that soil losses were not decreasing with increasing surface straw application rates. Any such decrease in soil loss was not large enough to be detected. Except for the increase from 0 to 0.5 t/ha, all other soil loss values showed numerical decreases with increasing rates of surface straw. The general trend was for lower soil loss values with increasing surface straw applications. Although results for three of the comparisons for adjacent application rates were so close together that statistical significance could not be shown, significant differences were shown when two or more adjacent treatments in lower ranges were compared with combinations of two or more adjacent treatments in the next higher ranges. For example, the combination of 0 and 0.5 t/ha was significantly greater at the 5% level than the combination of 1 and 2 t/ha. Scheffe's test, which allows for comparisons of groups of means selected after visual inspection of the data, was used for these comparisons.

The equation selected to represent the relationship between soil loss and surface straw is:

$$\text{Ln (S.L.)} = 6.66 - 0.302 \text{ (ST)}$$

where soil loss (S.L.) is in g/m^2 and surface straw is in t/ha. The relationship is shown graphically in Figure 13 with the natural log of soil loss plotted versus rates of surface straw.

Dry, Wet and Very Wet Runs

Tables 12, 13, and 14 show the soil losses from the dry, wet and very wet runs, respectively. An analysis of variance for each of these runs is shown in Table 15. In all three types of runs, the treatments of various rates of surface straw were significant when tested at the 5% level, but the effect of blocking was not significant.

The LSD tests showed a difference of 27, 37 and 40 g/m^2 was required to detect differences between pairs of means in the dry, wet and very wet runs, respectively. In the dry and very wet runs there were significant differences in pairs of means when there was at least a difference of 2 t/ha in surface straw, except for the comparison between 4 and 6 t/ha of surface straw. In the wet runs a difference of 4 t/ha of surface straw was required before differences in soil loss could be statistically detected between pairs of means.

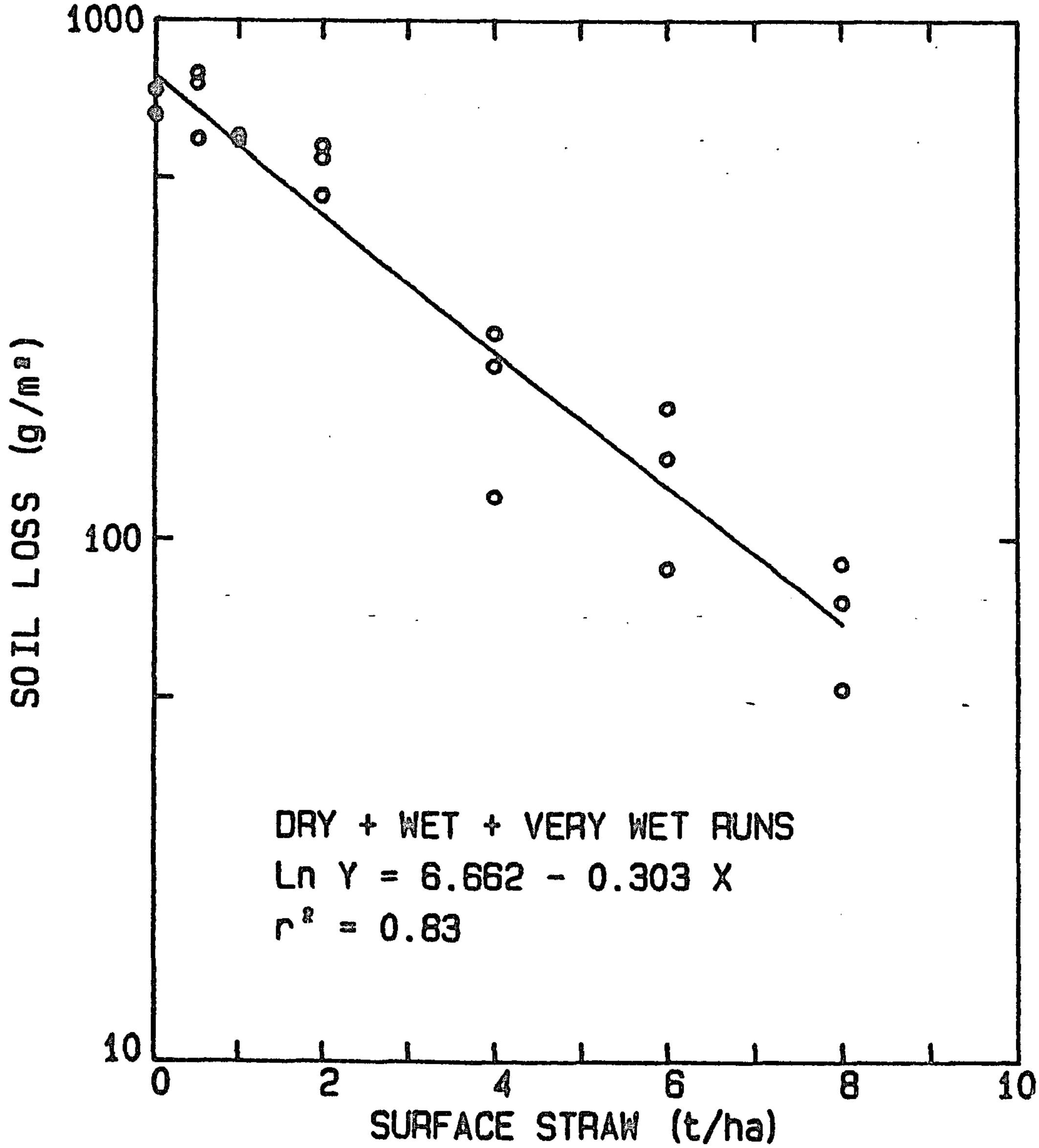

Figure 13. The relationship between soil loss (g/m^2) and surface straw (t/ha) for the sum of dry, wet and very wet runs.

Table 12. Soil loss from dry runs for different rates of surface straw applications.

	Soil				Losses
Surface Straw t/ha	Block 1 g/m^2	Block 2 g/m^2	Block 3 g/m^2	Total g/m^2	Average g/m^2
0	250	236	268	754	251
0.5	232	255	244	731	244
1	190	183	202	575	192
2	167	174	178	519	173
4	103	74	32	209	70
6	51	60	28	139	46
8	13	18	23	54	18
Total	1006	1000	975		

Table 13. Soil loss from wet runs for different rates of surface straw.

	Soil Losses				
Surface Straw t/ha	Block 1 g/m^2	Block 2 g/m^2	Block 3 g/m^2	Total g/m^2	Average g/m^2
0	168	204	215	587	196
0.5	227	246	142	615	205
1	206	201	196	603	201
2	223	190	168	581	194
4	77	77	52	206	69
6	67	41	37	145	48
8	22	44	32	98	33
Total	990	1003	842	2835	

Table 14. Soil loss (g/m^2) from very wet runs for different rates of surface straw (t/ha).

Surface Straw t/ha	Soil Losses Block 1 g/m^2	Block 2 g/m^2	Block 3 g/m^2	Total g/m^2	Average g/m^2
0	240	219	251	710	237
0.5	333	256	207	796	265
1	192	208	203	603	201
2	186	182	117	485	162
4	73	68	37	178	59
6	63	43	23	129	43
8	17	28	21	66	22
Total	1104	1004	859	2967	

Table 15. Analysis of variance for soil losses (g/m^2) from dry, wet and very wet runs for different rates of surface straw (t/ha).

Analysis of Variance (Dry Runs)

Source	Degree of Freedom	Sum of Squares	Mean Square	F	F(.05)
Total	20	170603	8530		
Straw	6	166434	27739	81.3	3.0
Blocks	2	77	38	0.1	3.9
Error	12	4092	341		

Analysis of Variance (Wet Runs)

Source	Degree of Freedom	Sum of Squares	Mean Square	F	F(.05)
Total	20	126400	6320		
Straw	6	116285	19381	29.7	3.0
Blocks	2	2285	1142	1.8	3.9
Error	12	7830	652		

Analysis of Variance (Very Wet Runs)

Source	Degree of Freedom	Sum of Squares	Mean Square	F	F(.05)
Total	20	190570			
Straw	6	177216	29536	39.3	3.0
Blocks	2	4336	2168	2.9	3.9
Error	12	9018	752		

The following equations were derived for the dry, wet and very wet runs:

Dry $\quad Ln(S.L.) = 5.63 - 0.335\ (ST),\ r^2 = 0.92$

Wet $\quad Ln(S.L.) = 5.46 - 0.259\ (ST),\ r^2 = 0.89$

Very Wet $Ln(S.L.) = 5.59 - 0.323\ (ST),\ r^2 = 0.92$

where S.L. equals soil loss in g/m^2 and ST is surface straw in t/ha. The equations are shown graphically in figures 14, 15, and 16 for the dry, wet and very wet runs, respectively.

Although dry runs were 30 minutes longer than other runs, their soil losses were not statistically greater because extra time was required for the initiation of runoff and for the rising side of the runoff hydrograph. About 12 minutes elapsed before there was any runoff for the 0 and 0.5 t/ha rates of surface straw. This time interval increased to about 16 minutes for the 1 and 2 t/ha rates, and 20 minutes for the 4, 6 and 8 t/ha rates. Equilibrium rates of runoff usually occurred in the wet or very wet runs.

Initial soil moisture contents for dry runs were very low, about 1.5%. The soil surface moisture contents following dry runs were about equal to those following wet and very wet runs (Table 16). The soil surface moisture contents generally increased with increasing rates of surface straw.

Since initial and final soil moisture contents for wet and very wet runs were similar, time periods were equal for these runs, and there was no appreciable evidence of surface changes between these runs, it

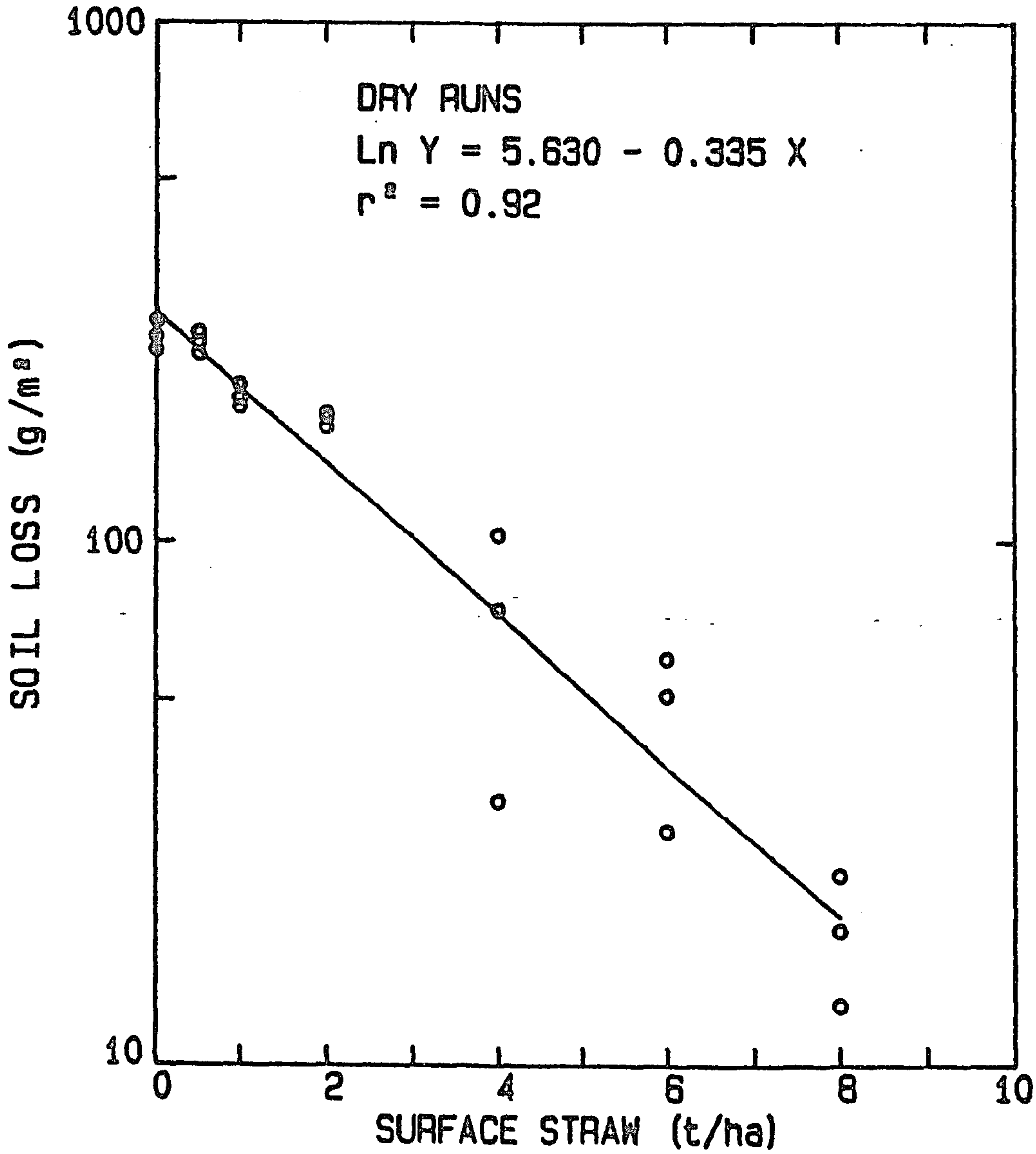

Figure 14. The relationship between soil loss (g/m^2) and surface straw (t/ha) for dry runs.

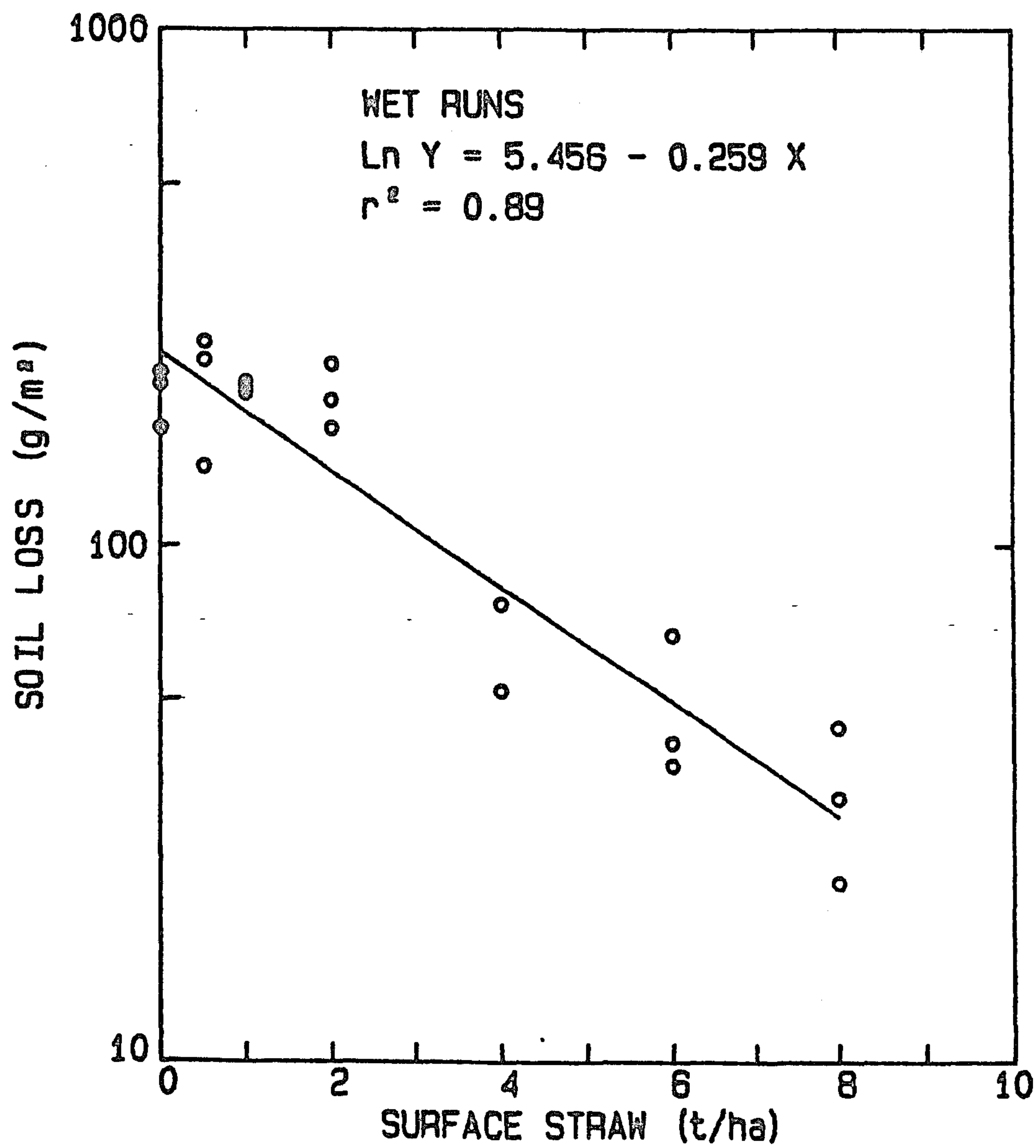

Figure 15. The relationship between soil loss (g/m^2) and surface straw (t/ha) for wet runs.

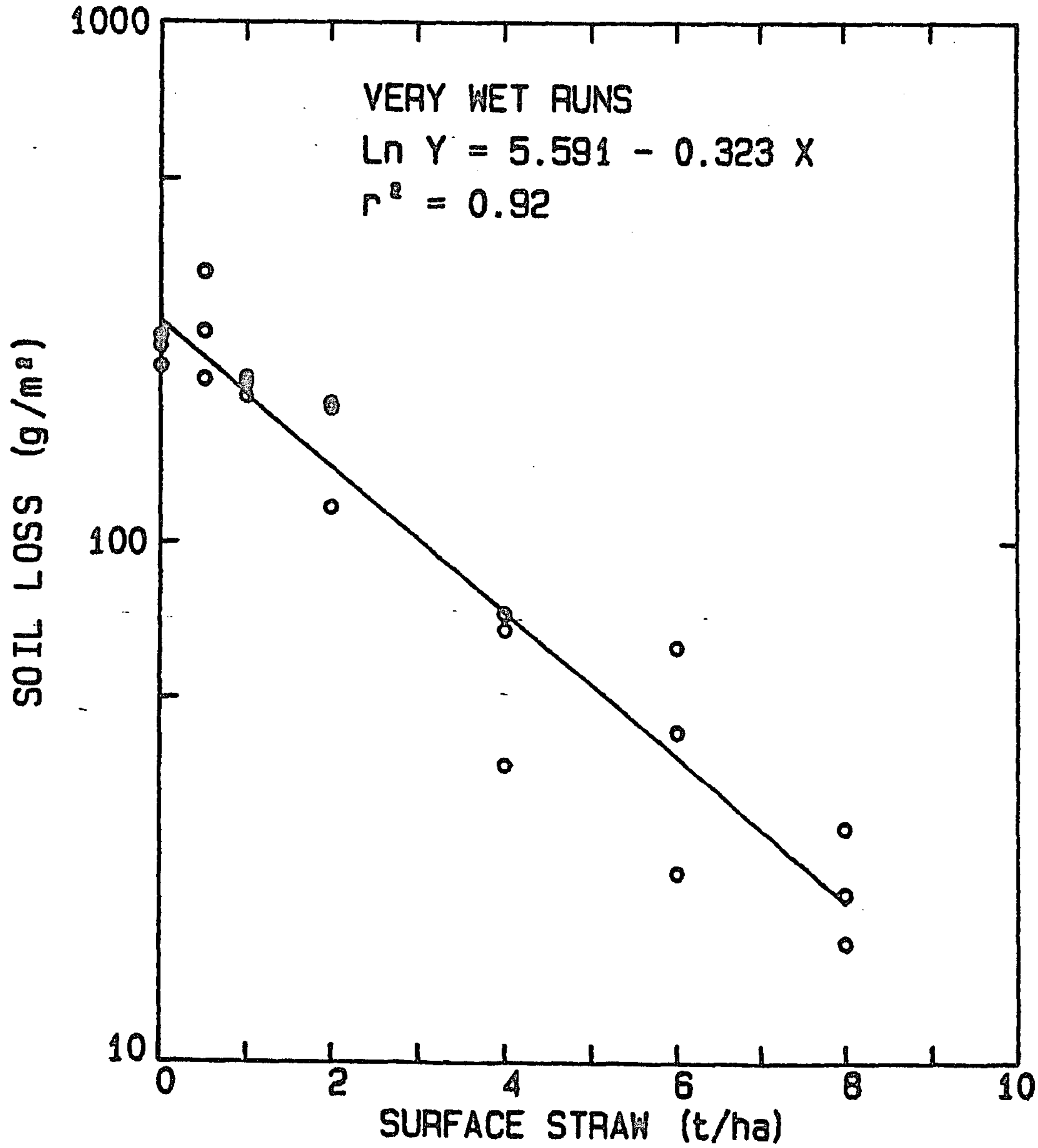

Figure 16. The relationship between soil loss (g/m^2) and surface straw (t/ha) for very wet runs.

Table 16. Average soil surface moisture contents following dry, wet and very wet runs for various rates of surface straw.

	AVERAGE SOIL SURFACE MOISTURE CONTENT		
Surface Straw t/ha	After Dry Runs %	After Wet Runs %	After Very Wet Runs %
0	30	32	31
0.5	33	32	33
1	31	32	32
2	35	32	34
4	35	35	36
6	38	36	36
8	37	37	38

follows that soil losses from wet and very wet runs would be similar. Differences between soil losses from wet and very wet runs were not significant, as shown by an analysis of variance (Table 17) in which data were arranged in two blocks- one for wet runs, and the other for very wet runs.

There was a rapidly rising hydrograph for runoff at the beginning of very wet runs, usually reaching final runoff rates of the wet runs after the first four minutes of very wet runs. Thus the sum of soil losses from wet and very wet runs closely approximated that which would have occurred with a continuous "wet" run of 60 minutes. The equation for the summation of soil loss from wet and very wet runs was:

$$\text{Ln (S.L.)} = 6.22 - 0.29 \text{ (ST)}, \; r^2 = 0.92$$

where soil loss (S.L.) is in g/m^2 and surface straw (ST) is in t/ha.

The sum of soil losses from wet and very wet runs was compared to soil losses from dry runs. Thus soil losses during equal, 60-minute time periods were compared for which there were two very different initial soil moisture contents. Obviously, the sum of soil losses from the wet and very wet runs should be greater than from dry runs, as was verified by an analysis of variance (Table 18).

The analysis of variance showed a significant interaction between type of run and surface straw treatments. Physical evidence of the interaction can best be seen by expressing the equation for these two types of runs in exponential form and comparing their graphical

Table 17. Analysis of variance for soil loss (g/m^2) from seven rates of surface straw (0 to 8 t/ha) with data arranged in two blocks: soil loss from wet runs in one block and soil loss from very wet runs in the second block.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	41	317385			
Straw	6	284053	47342	56.49	2.44
Type of Run (Wet or Very Wet)	1	415	415	0.50	4.20
Interaction	6	9447	1574	1.88	2.44
Error	28	23470	838		

Table 18. Analysis of variance for soil loss (g/m^2) for various rates of surface straw (0 to 8 t/ha) for 60-minute dry runs and the sum of wet and very wet runs.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	41	967316			
Straw	6	671423	111904	72.38	2.44
Type of Run (Dry vs. Sum of Wet and Very Wet)	1	189477	189477	122.55	4.20
Interaction	6	63118	10520	6.80	2.44
Error	28	43298	1546		

representations (Figure 17). As surface straw increased, soil losses decreased for both 60-minute periods; however, curves representing the relationship between soil loss and surface straw for the two types of runs are not parallel. At the upper limit of 8 t/ha of surface straw, the curves have not yet converged but are much closer together. At 0 t/ha of surface straw, average soil loss from the 60-minute dry runs was exceeded by that from the combined 30-minute wet and very wet runs by about 224 g/m^2. At 8 t/ha of surface straw this difference has been reduced to only about 28 g/m^2, but the ratio of soil loss from the wetter run to that from the dry run has increased from about 1.8 to 2.3.

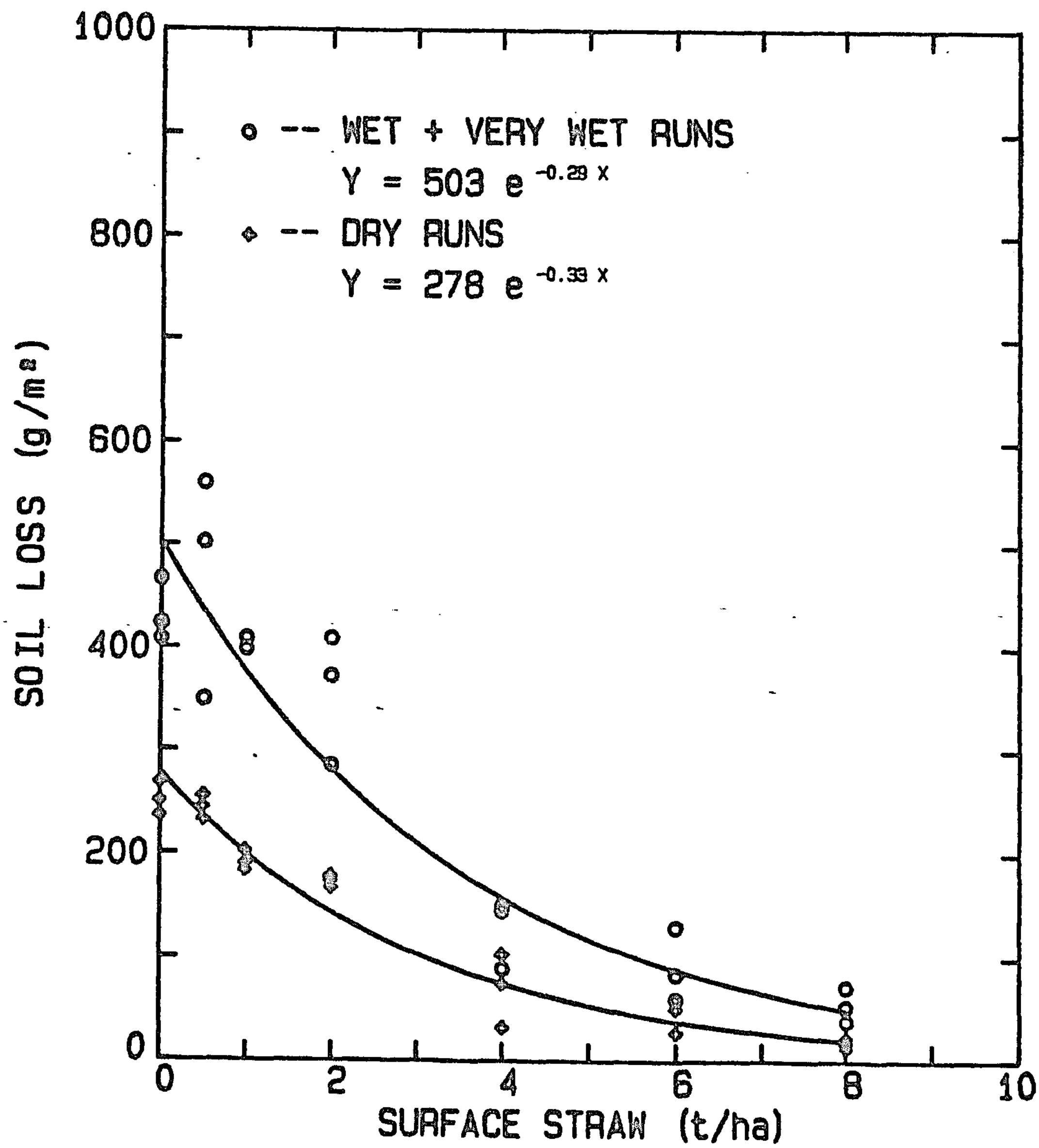

Figure 17. Comparison of equations relating, soil loss (g/m^2) and surface straw (t/ha) for a 60-minute initial dry run and for the sum of two 30-minute (wet + very wet) runs.

Effects of Incorporated Straw on Runoff

A completely randomized design was used to test the effects of incorporated straw on runoff. There were five replications with 0 t/ha of incorporated straw and five replications with 9 t/ha of incorporated straw. Two replications were used for incorporated rates of 2.2, 4.5 and 6.7 t/ha.

The sum of runoff values from dry, wet and very wet runs are presented in Table 19 for each replication of the five treatments of incorporated straw rates. Average runoff rates from the sum of dry, wet and very wet runs was 7.07, 7.46, 7.44, 7.52 and 7.56 cm for incorporated rates of 0, 2.2, 4.5, 6.7 and 9 t/ha, respectively. The S.E. of the difference in means, using the error mean square in the analysis of variance (Table 20) as the variance per sample, for comparisons of means with 5 and 5, 5 and 2, and 2 and 2 replications was 0.164, 0.217 and 0.259, respectively. The t values (two-tailed, 5%, 11 degrees of freedom) of 2.201 times these respective S.E. values gave LSD values of 0.36, 0.26 and 0.57 cm, respectively.

The difference in mean runoff values for 0 and 9 t/ha of incorporated straw was slightly significant, but comparisons for any other pairs of means were not statistically significant. An analysis of variance (Table 20) indicates no effect of incorporated straw at the 5% level of significance on the sum of runoff values from dry, wet and very wet runs. Nevertheless, a linear component for the effect of treatments was statistically significant. The linear regression

Table 19. Runoff from each replication for dry, wet and very wet runs for incorporated rates of straw.

Incorporated Straw t/ha	Runoff Dry Runs (cm)	Wet Runs (cm)	Very Wet Runs (cm)	Total (cm)
0	2.70	1.86	2.50	7.06
0	2.73	1.91	2.54	7.18
0	2.63	1.89	2.53	7.05
0	2.54	2.04	2.58	7.16
0	2.36	1.98	2.54	6.88
2.2	3.04	1.72	2.50	7.26
2.2	2.92	2.18	2.57	7.67
4.5	2.82	2.16	2.56	7.54
4.5	2.65	1.98	2.71	7.34
6.7	3.33	2.08	2.44	7.85
6.7	2.88	1.85	2.46	7.19
9.0	3.31	2.05	2.51	7.87
9.0	2.90	2.00	2.32	7.22
9.0	2.86	1.94	2.45	7.25
9.0	3.11	2.12	2.52	7.75
9.0	3.00	2.20	2.49	7.69

Table 20. Analysis of variance for runoff (cm) from the sum of dry, wet and very wet run for incorporated straw rates of 0, 2.2, 4.5, 6.7, and 9 t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	15	1.4471			
Incorporated	4	0.7078	.1770	2.63	3.36
Error	11	0.7393	.0672		

was:

$$R.O. = 7.15 + 0.05 \text{ INC. ST.}$$

where runoff (R.O.) was in cm and incorporated straw (INC. ST.) was in t/ha. The r^2 for this equation was only 0.39. The S.E. of estimate was 0.25 cm, or only slightly less than the standard deviation (0.31 cm) of all samples for the entire range of incorporated straw rates. Only about 30% of the variation in runoff was associated with the linear regression on incorporated straw. The coefficient of variation for the entire data set was only 4.2%, thus any significance attached to any reduction in variation due to regression serves no practical purpose. For all practical purposes, and certainly in regard to any subsequent effect of soil loss, there was no correlation between runoff from the sum of dry, wet and very wet runs and rates of incorporated straw. The lack of correlation is shown graphically in Figure 18.

Dry, Wet and Very Wet Runs

Runoff data for each replication of the five treatments of incorporated straw are presented in Table 19. Table 21 shows the average runoff value for each rate of incorporated straw for each type of run. Average runoff ranged from 2.59 to 3.04, 1.94 to 2.07 and 2.45 to 2.64 cm for the entire range of incorporated straw rates in the dry, wet, and very wet runs, respectively.

Although variation in the data was relatively low, an analysis of variance (Table 22) for each type of run indicated that the effects of incorporated straw on runoff was slightly significant at the 5% level

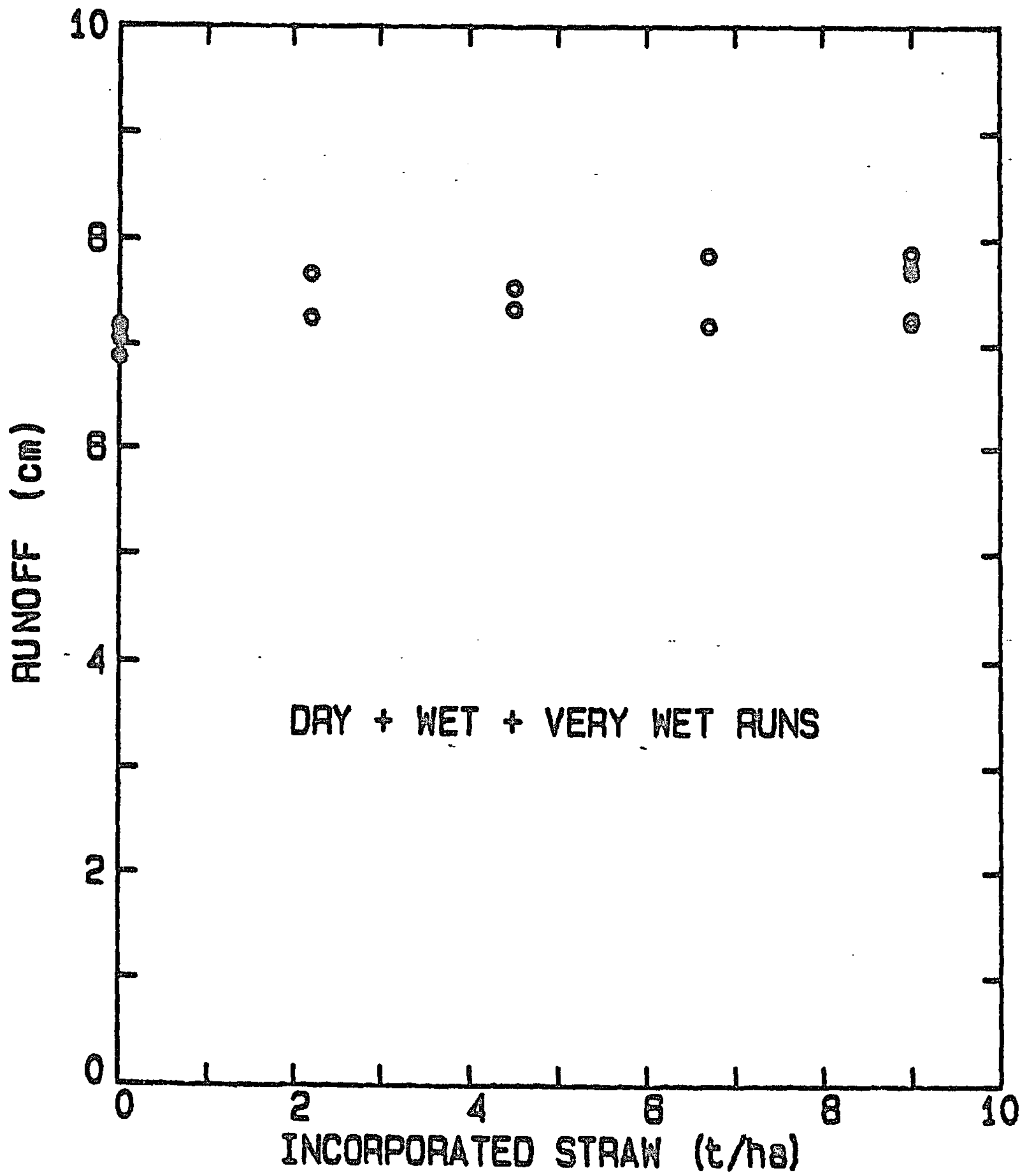

Figure 18. Runoff (cm) plotted versus incorporated straw (t/ha) for the sum of dry, wet and very wet runs.

Table 21. Average runoff for dry, wet, and very wet runs for each rate of incorporated straw.

Incorporated Straw (t/ha)	No. Reps.	Average Runoff Dry (cm)	Wet (cm)	Very Wet (cm)	Total (cm)
0	5	2.59	1.94	2.54	7.07
2.2	2	2.98	1.95	2.54	7.47
4.5	2	2.74	2.07	2.64	7.45
6.7	2	3.10	1.96	2.45	7.51
9.0	5	3.04	2.06	2.46	7.56

Table 22. Analysis of variance for runoff (cm) for dry, wet and very wet runs for incorporated straw rates of 0, 2.2, 4.5, 6.7 and 9 t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
		DRY RUNS			
Total	15	1.0370			
Inc. Straw	4	0.6941	.1735	5.56	3.36
Error	11	0.3429	.0312		
		WET RUNS			
Total	15	0.2679			
Inc. Straw	4	0.0569	.0142	0.74	3.36
Error	11	0.2111	.0192		
		VERY WET RUNS			
Total	15	0.1008			
Inc. Straw	4	0.0569	.0142	3.55	3.36
Error	11	0.0439	.0040		

for the dry and very wet runs. For all practical purposes, these statistically significant results are misleading.

None of the pairs of means in the dry runs for incorporated rates of 2.2 through 9 t/ha were significantly different. The mean runoff value of 2.59 cm at 0 t/ha of incorporated straw was significantly different from the mean value of 3.04 cm at 9 t/ha. The mean value at 0 t/ha was also significantly different from the mean value of 2.98 cm at 2.2 t/ha as well as the 3.10 cm at 6.7 t/ha. The S.E. of difference for comparing the difference in means at 0 and 9 t/ha was 0.112 cm resulting in an LSD of 0.25 cm. The S.E. of difference between two means at 0 and 2.2 t/ha as well as the difference between 0 and 6.7 t/ha was 0.148 cm, resulting in a LSD value of 0.33 cm.

In general, there was just not much variation in the data set for the dry runs. The variance about the mean of the entire data set was only 0.0691. After taking into account the variation due to the effect of incorporated straw, the variance was further reduced to 0.0312. The F value of 5.56 resulted in statistical significance. But the low numerical value of the total variance, the small number of replications and the lack of significant differences in any of the pairs of means for 2.2 through 9.0 t/ha of incorporated straw should be taken into account in determining the meaning of the statistical significance. From a practical standpoint, a strong enough case has not been made to conclude that runoff from dry runs is affected by changes in incorporated rates of straw.

Similar comments apply somewhat to results for the very wet runs. An analysis of variance indicated a slight significance for the effect on runoff of incorporated rates of straw. Yet the variance of the data set was even less than in dry runs. The variance for runoff in the very wet runs was only 0.0067, which in turn was further reduced to only 0.0040 when the effects of incorporated straw were removed. In this case an F value of 3.55 was only slightly higher than that of 3.36 required for significance at the 5% level.

Comparisons of differences in pairs of means show that none were statistically different. Mean values of runoff at 0 and 2.2 t/ha were equal. The difference in mean values of runoff at 6.7 and 9 t/ha was only 0.01 cm, and the highest mean value at 4.5 t/ha was only 0.19 cm greater than the lowest mean at 6.7 t/ha.

The treatment sum of squares was subdivided into two components, a linear regression component and deviations from linear regression (Table 23). The linear component was slightly significant, and deviations from linear regression were not significant. When the deviation sum of squares were combined with the error sum of squares, giving 14 degrees of freedom for error, the linear regression approached but fell short of significance at the 5% level.

Figures 19, 20, and 21 show runoff values plotted versus rates of incorporated straw for the dry, wet and very wet runs. These figures illustrate graphically the lack of correlation between runoff and rates of incorporated straw for the dry, wet and very wet runs.

Table 23. Analysis of variance for linear regression of runoff (cm) from very wet runs for incorporated straw rates of 0, 2.2, 4.5, 6.7 and 9.0 t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	15	0.1008			
Incorporated	4	0.0569	0.0142	3.55	3.36
Linear Reg.	1	0.0213	0.0213	5.32	4.84
Deviation	3	0.0356	0.0119	2.98	3.59
Error	11	0.0439	0.0040		

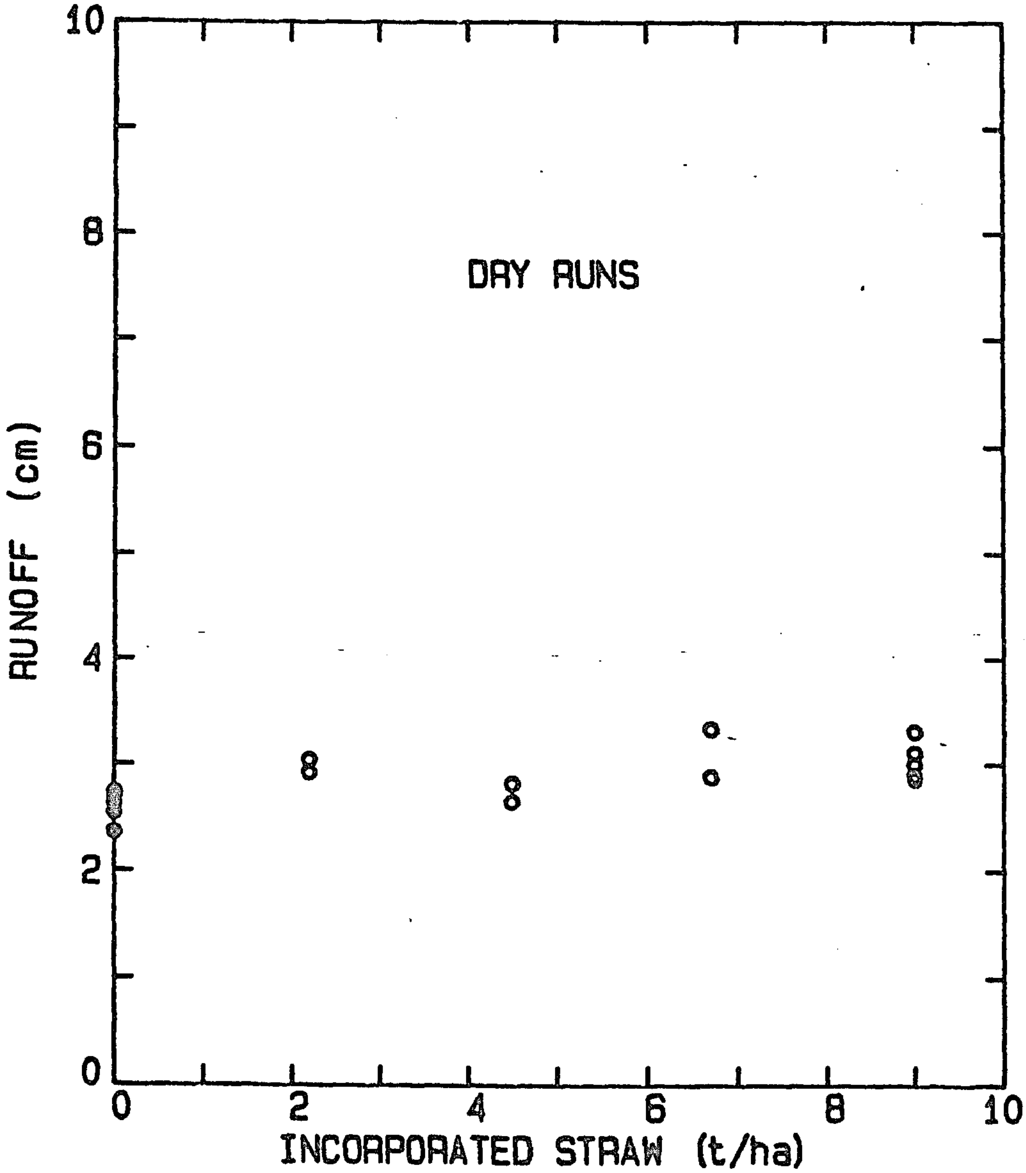

Figure 19. Runoff (cm) plotted versus incorporated straw (t/ha) for dry runs.

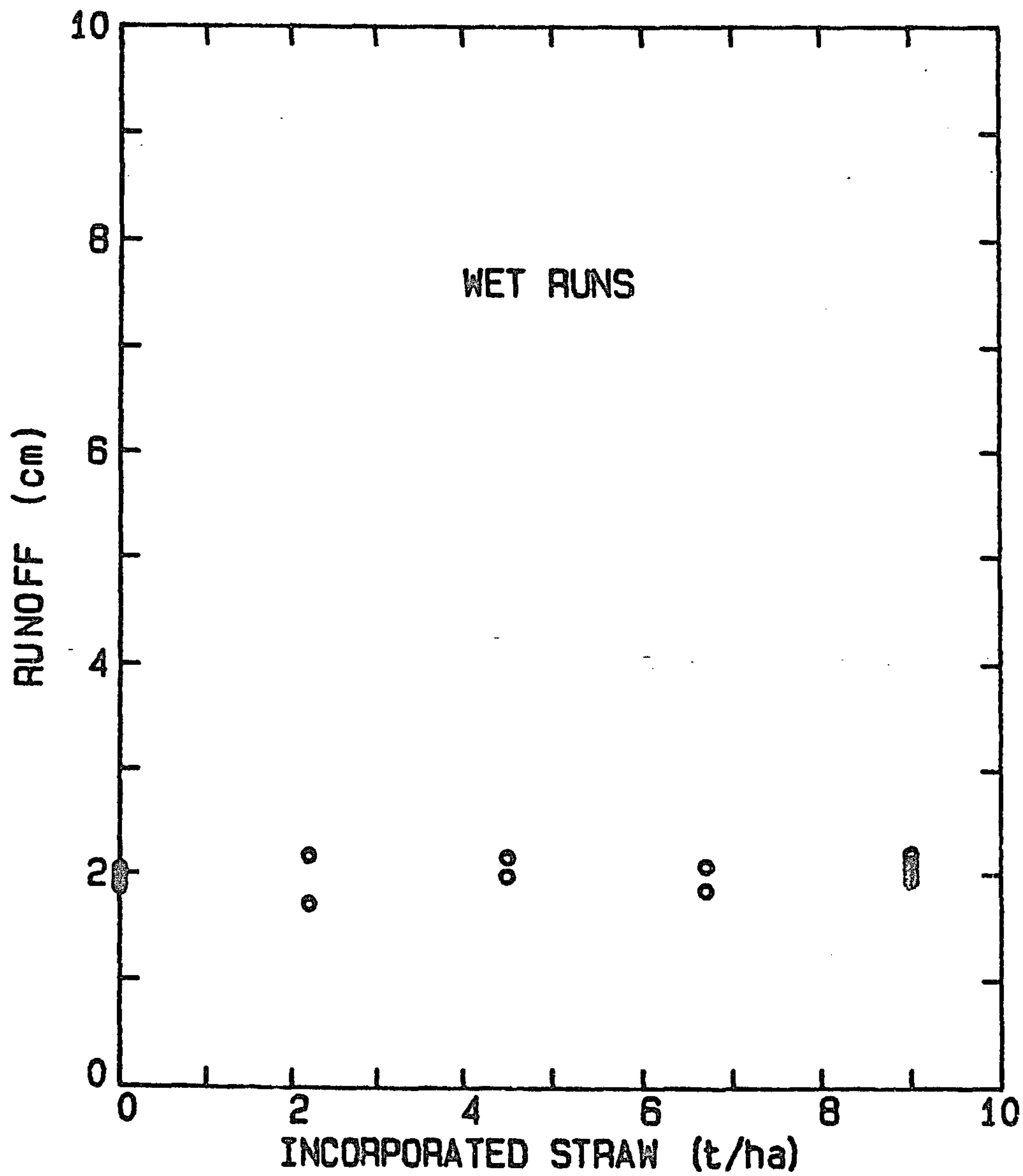

Figure 20. Runoff (cm) plotted versus incorporated straw (t/ha) for wet runs.

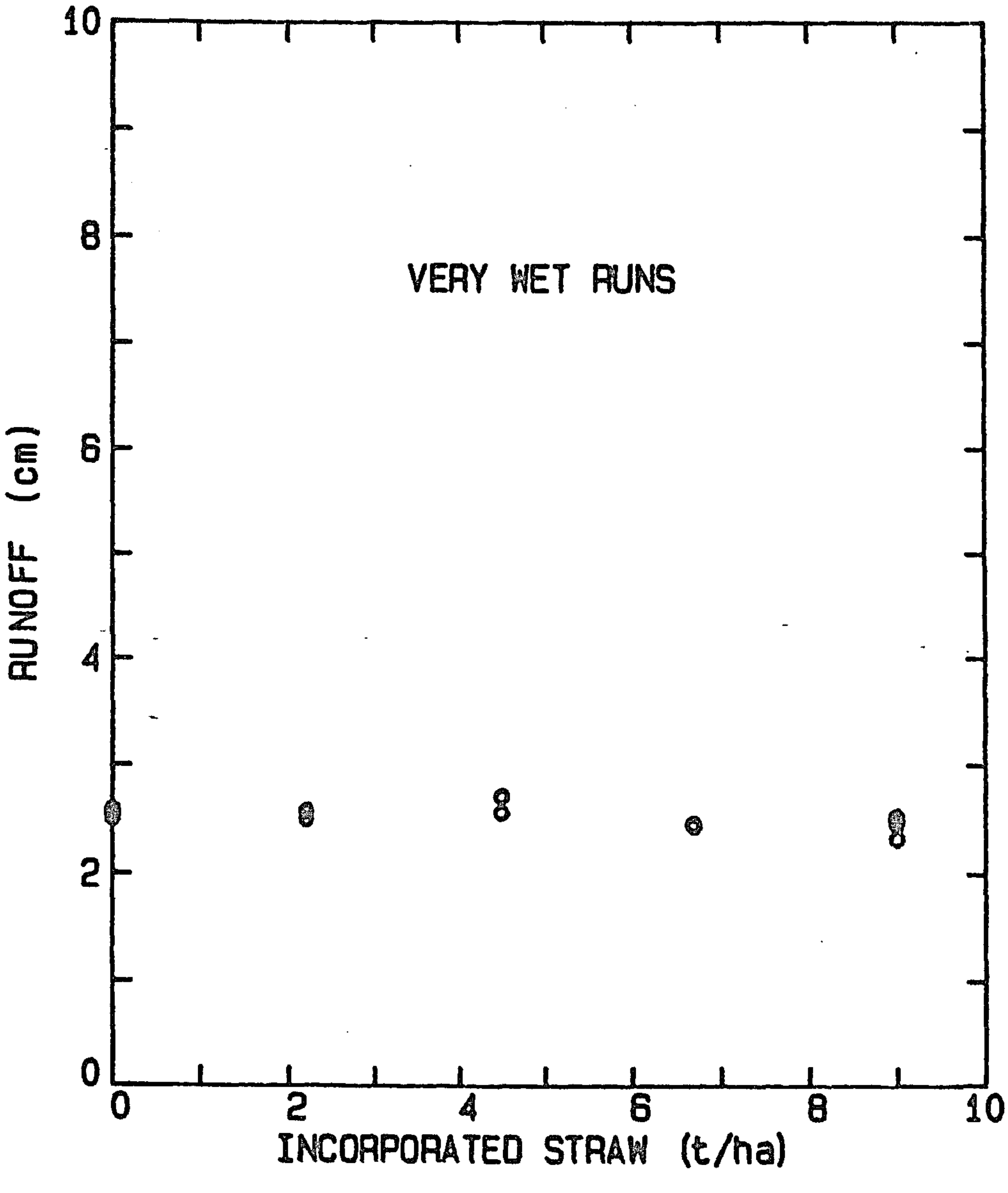

Figure 21. Runoff (cm) plotted versus incorporated straw (t/ha) for very wet runs.

Table 24 shows the average soil surface moisture contents following dry, wet and very wet runs were about the same. These data also reveal that increasing rates of incorporated straw did not cause any change in the soil surface moisture contents.

Table 24. Average soil surface moisture contents after dry, wet and very wet runs for various incorporated rates of straw.

	AVERAGE SOIL SURFACE MOISTURE CONTENT		
Surface Straw t/ha	After Dry Runs %	After Wet Runs %	After Very Wet Runs %
0	29	31	32
2.2	30	30	30
4.5	29	30	30
6.7	28	30	31
9.0	29	31	31

Effects of Incorporated Straw on Soil Loss

A completely randomized design was used to test the effects of incorporated straw on soil loss. There were five replications with 0 t/ha amounts of incorporated straw and five replications with 9 t/ha of incorporated straw. Two replications were used for incorporated rates of 2.2, 4.5 and 6.7 t/ha. Preliminary investigations involving several runs indicated no effect of incorporated straw on soil loss. This was the reason for using more replications at the 0 and 9 t/ha rates of incorporated straw.

Soil loss values for the sum of dry, wet and very wet runs for each replication of each rate of incorporated straw are presented in Table 25. Average soil loss for the sum of dry, wet and very wet runs was 814, 869, 826, 883 and 843 g/m^2 for incorporated rates of 0, 2.2, 4.5, 6.7 and 9 t/ha, respectively. An analysis of variance (Table 26) indicates that the effect of incorporated straw on soil loss was not significant.

Mean values of soil loss for 0 and 9 t/ha of incorporated rates of straw were compared. Using a pooled variance for soil loss values from these two rates of incorporated straw gave a S.E. of difference between the means of 14.14 g/m^2. The difference between the means, 29.2 g/m^2, divided by 14.14 g/m gave a t value of 2.07. This value was less than the value of 2.31 (two-tailed, 5% level, 8 degrees of freedom) required for significance.

Table 25. Soil loss values for each replication for dry, wet and very wet runs for incorporated straw rates of 0, 2.2, 4.5, 6.7, and 9.0 t/ha.

Incorporated Straw (t/ha)	Soil Loss			
	Dry Runs (g/m^2)	Wet Runs (g/m^2)	Very Wet Runs (g/m^2)	Total (g/m^2)
0	307	183	294	784
0	293	213	306	812
0	236	259	284	779
0	257	276	342	875
0	256	235	329	820
2.2	407	195	323	925
2.2	305	232	276	813
4.5	336	197	277	810
4.5	275	195	372	842
6.7	395	235	275	905
6.7	314	218	329	861
9.0	397	235	275	907
9.0	355	193	314	862
9.0	330	201	249	780
9.0	354	191	261	806
9.0	312	221	328	861

Table 26. Analysis of variance for soil loss (g/m^2) from the sum of dry, wet and very wet runs for incorporated rates of straw of 0, 2.2, 4.5, 6.7 and 9 t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	15	32960			
Inc. Straw	4	9203	2301	1.07	3.36
Error	11	23757	2160		

Another way of comparing these means was by using the S.E. of the difference between the means that is calculated using the error mean square (S^2) from the analysis of variance. This S.E. was equal to the square root of $(2)(S^2)/5$ or 29.39 g/m^2. The ratio of the difference between the means and this S.E. value gave a t value of 0.99, less than the value of 2.20 (two-tailed, 5% level, 11 degrees of freedom) required for significance.

The lowest and highest means occurred at incorporated straw rates of 0 and 6.7 t/ha, respectively. The S.E. of the difference between these two means was equal to the square root of $(S^2)(1/r_1 + 1/r_2)$, where r_1 and r_2 was the number of replications for each of the two levels of incorporated straw, and S^2, with 11 degrees of freedom, was the error mean square from the analysis of variance. The S.E. of the difference between these two means was equal to 38.88. Dividing the difference between the two means by the S.E. gave a t value of 1.77, also less than that required for significance. Using the above procedure, every possible combination of differences between pairs of means were tested and found to be insignificant.

Lack of correlation between soil loss and rate of incorporated straw is illustrated graphically in Figure 22. A linear regression obtained by the method of least squares yielded an r^2 value near zero and a slope coefficient for which the null hypothesis of zero slope could not be rejected at the 5% level.

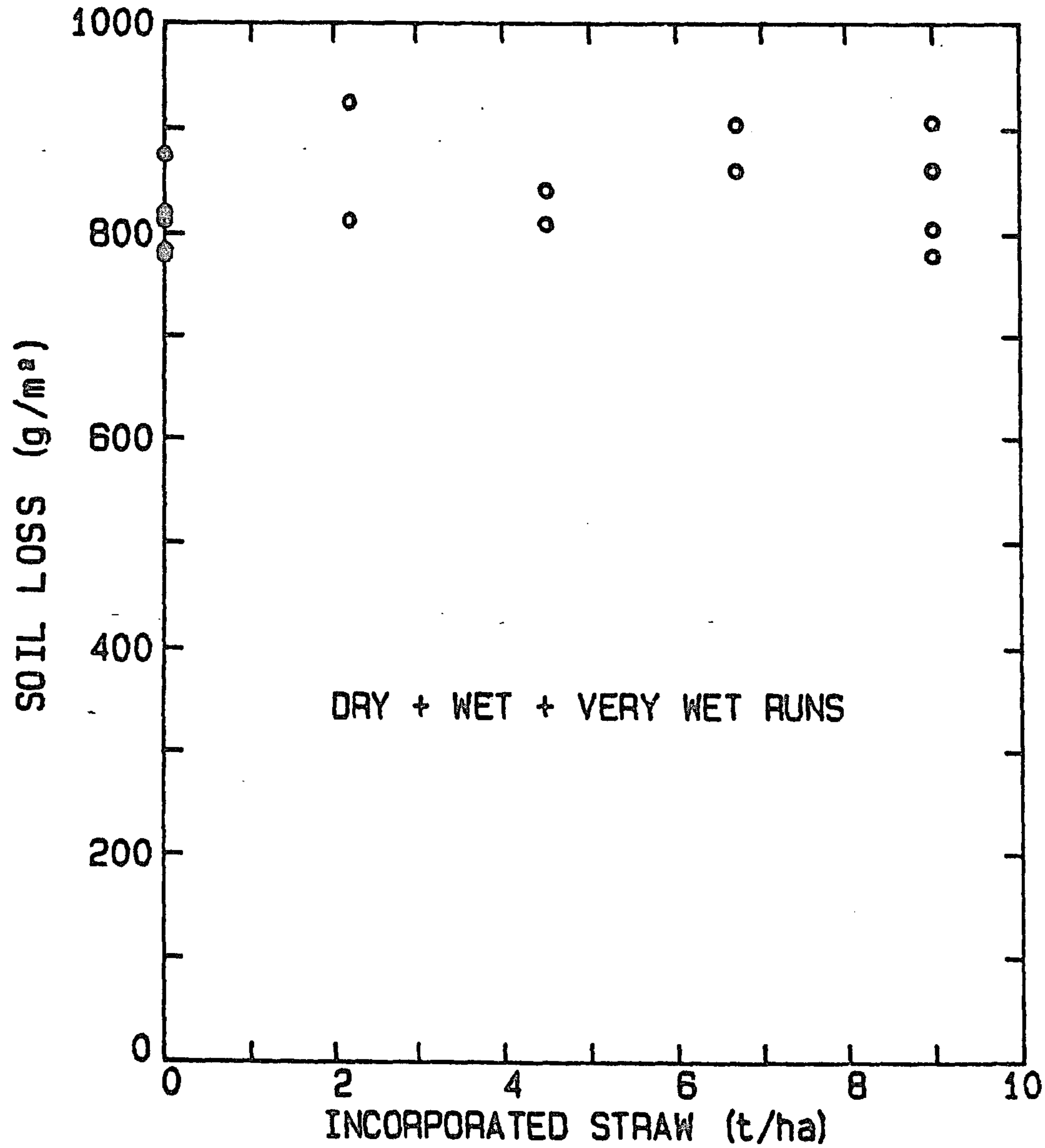

Figure 22. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for the sum of dry, wet and very wet runs.

Dry, Wet and Very Wet Runs

Soil loss values for dry, wet and very wet runs for each replication of each rate of incorporated straw are given in Table 25. Average values of soil loss for each rate of incorporated straw for each type of run are presented in Table 27. Except for dry runs, mean values of soil losses did not change very much for the different rates of incorporated straw. Averages ranged from 270 to 356, 196 to 233, and 300 to 324 g/m^2 for the range of incorporated straw rates in dry, wet and very wet runs, respectively. An analysis of variance for each type of run (Table 28) indicates that the effect of incorporated straw on soil loss was significant at the 5% level only in the dry runs, but even then the F value only slightly exceeded that required for significance.

Average soil loss values for dry runs were 270, 356, 305, 354 and 350 g/m^2 for incorporated rates of 0, 2.2, 4.5, 6.7 and 9 t/ha, respectively. Obviously, average soil loss values for incorporated rates of 2.2, 6.7, and 9 t/ha were not significantly different. The reason for the slight significance indicated in the analysis of variance for the effect of incorporated straw on soil loss had to be caused by either or both of the lower values of soil loss for 0 and 4.5 t/ha rates of incorporated straw.

Using the error mean square from the analysis of variance in formulas previously shown gave S. E. values of 25.48, 33.71 and 40.29 g/m^2 for differences in means with 5 and 5, 5 and 2, and 2 and 2

Table 27. Average soil loss values for each type of run and each rate of incorporated straw.

Incorporated Straw (t/ha)	No. Reps.	Average Soil Loss		
		Dry Runs (g/m^2)	Wet Runs (g/m^2)	Very Wet Runs (g/m^2)
0	5	270	233	311
2.2	2	356	214	300
4.5	2	305	196	324
6.7	2	354	226	302
9.0	5	350	208	285

Tables 28. Analysis of variance for soil loss (g/m^2) from dry, wet and very wet runs for incorporated rates of straw of 0, 2.2, 4.5, 6.7, and 9 t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
		DRY RUNS			
Total	15	40224			
Inc. Straw	4	22369	5592	3.45	3.36
Error	11	17855	1623		
		WET RUNS			
Total	15	10504			
Inc. Straw	4	2783	696	0.99	3.36
Error	11	7721	702		
		VERY WET RUNS			
Total	15	16872			
Inc. Straw	4	2808	702	0.55	3.36
Error	11	14064	1279		

replications, respectively. A t value (two-tailed, 5% level, 11 degrees of freedom) of 2.201 times each of the above S.E. values gave LSD values of 56, 74 and 89 g/m^2 for comparing means with 5 and 5, 5 and 2, and 2 and 2 replications, respectively.

Use of the LSD values indicated no significant differences between any of the means for incorporation rates of 2.2 through 9 t/ha. The mean value of soil loss for zero t/ha of incorporated straw was significantly different from each of the means at 2.2, 6.7 and 9 t/ha, but not that at 4.5 t/ha.

Figures 23, 24 and 25 show the soil loss values for each rate of incorporated straw for dry, wet and very wet runs, respectively. There was no correlation between soil loss and incorporated rates of straw during the wet and very wet runs. There appeared to be no significant correlation between soil loss and incorporated straw in dry runs when values at 0 t/ha of incorporated straw were omitted. Even with inclusion of the 0 t/ha rate the slope of the linear regression was only slightly significant. The treatment sum of squares was divided into linear, quadratic, cubic and quartic components. Only the linear component was significant. The linear regression was:

$$\text{S.L.} = 284.7 + 8.0 \text{ INC. ST.}$$

where soil loss (S.L.) was in g/m^2 and incorporated straw (INC. ST.) was in t/ha. The r^2 value for this equation was only 0.35. The S.E. of estimate was 43.1 g/m^2. The analysis of variance for the regression is presented in Table 29. The estimated variance of

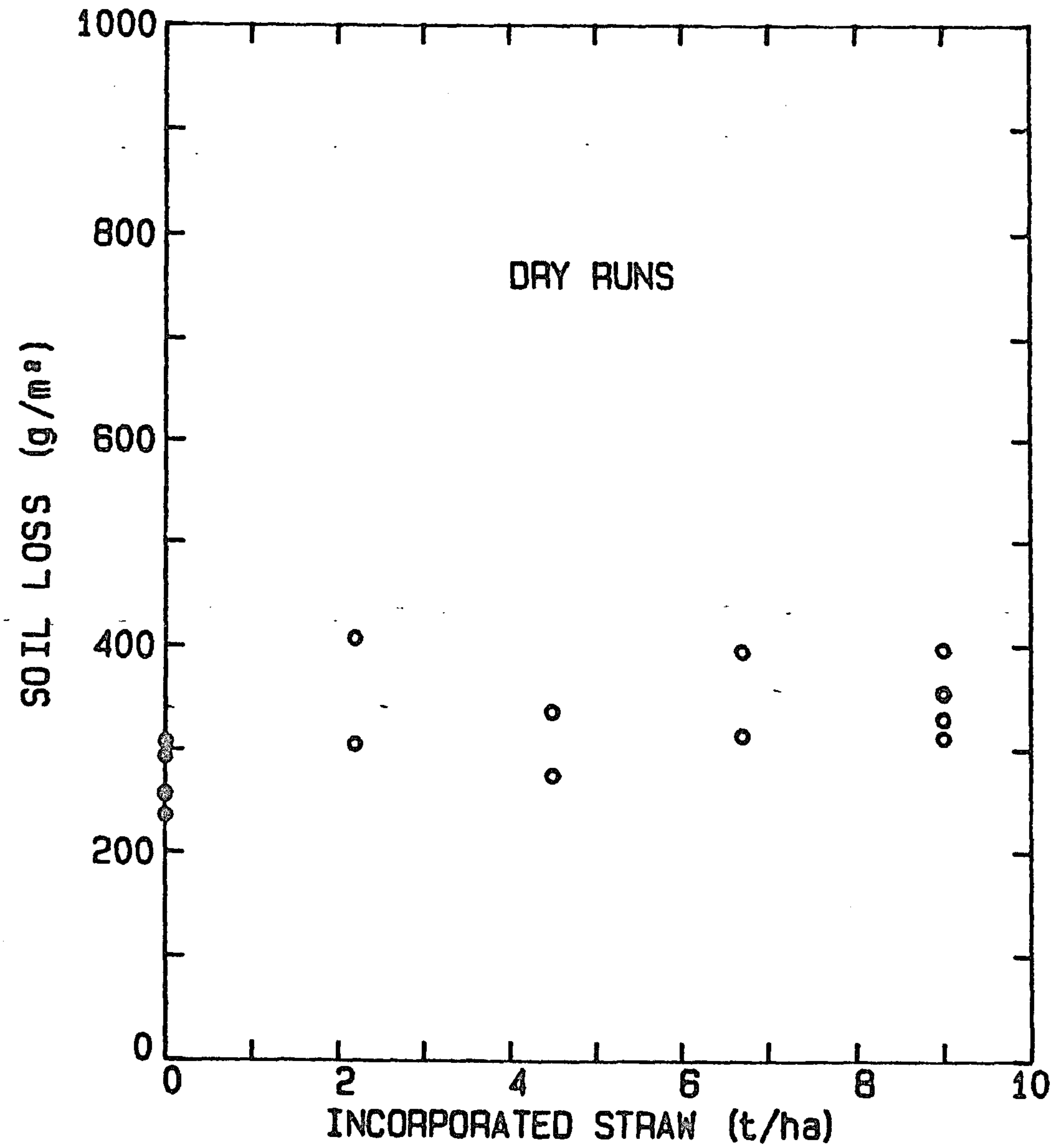

Figure 23. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for dry runs.

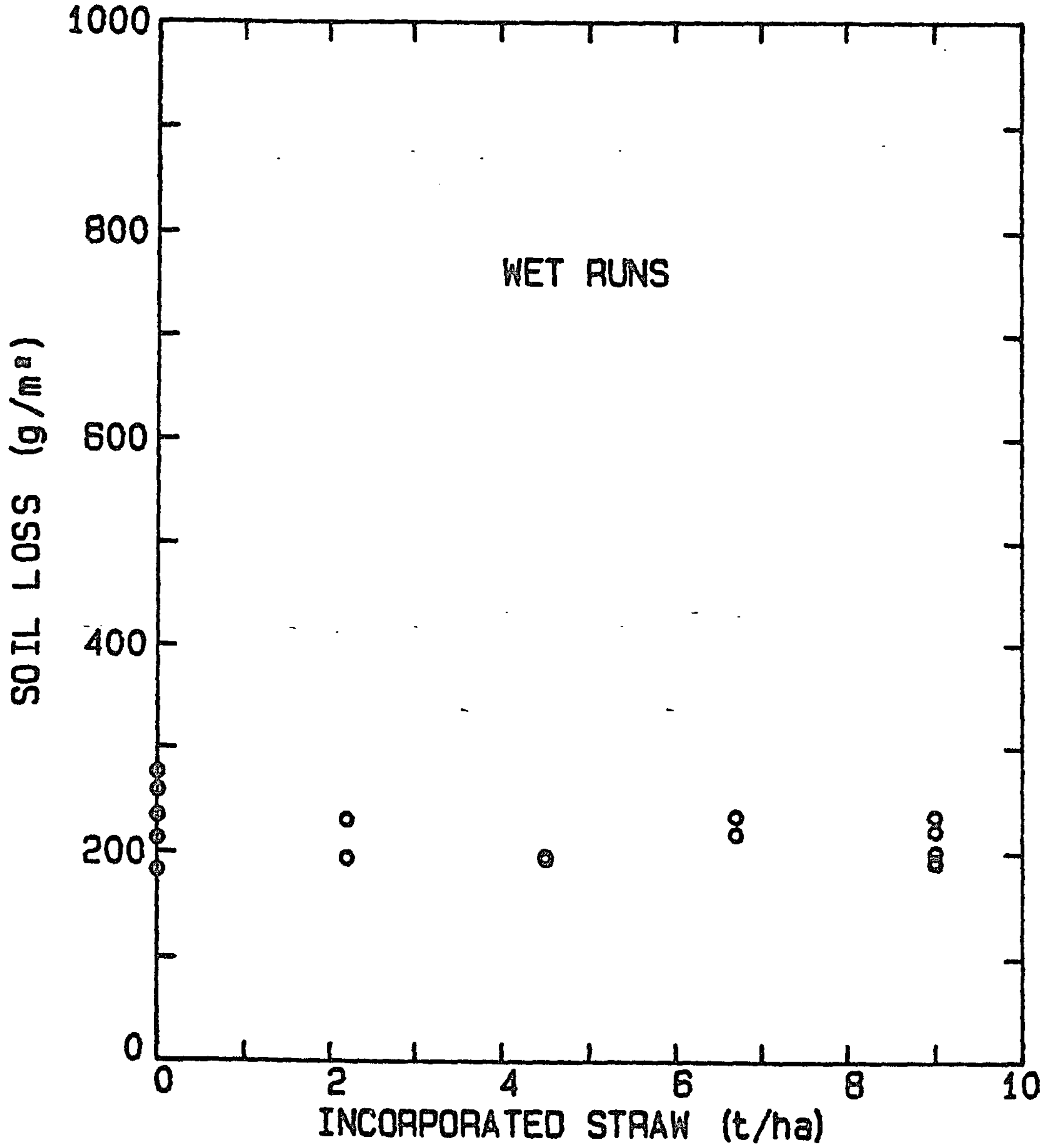

Figure 24. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for wet runs.

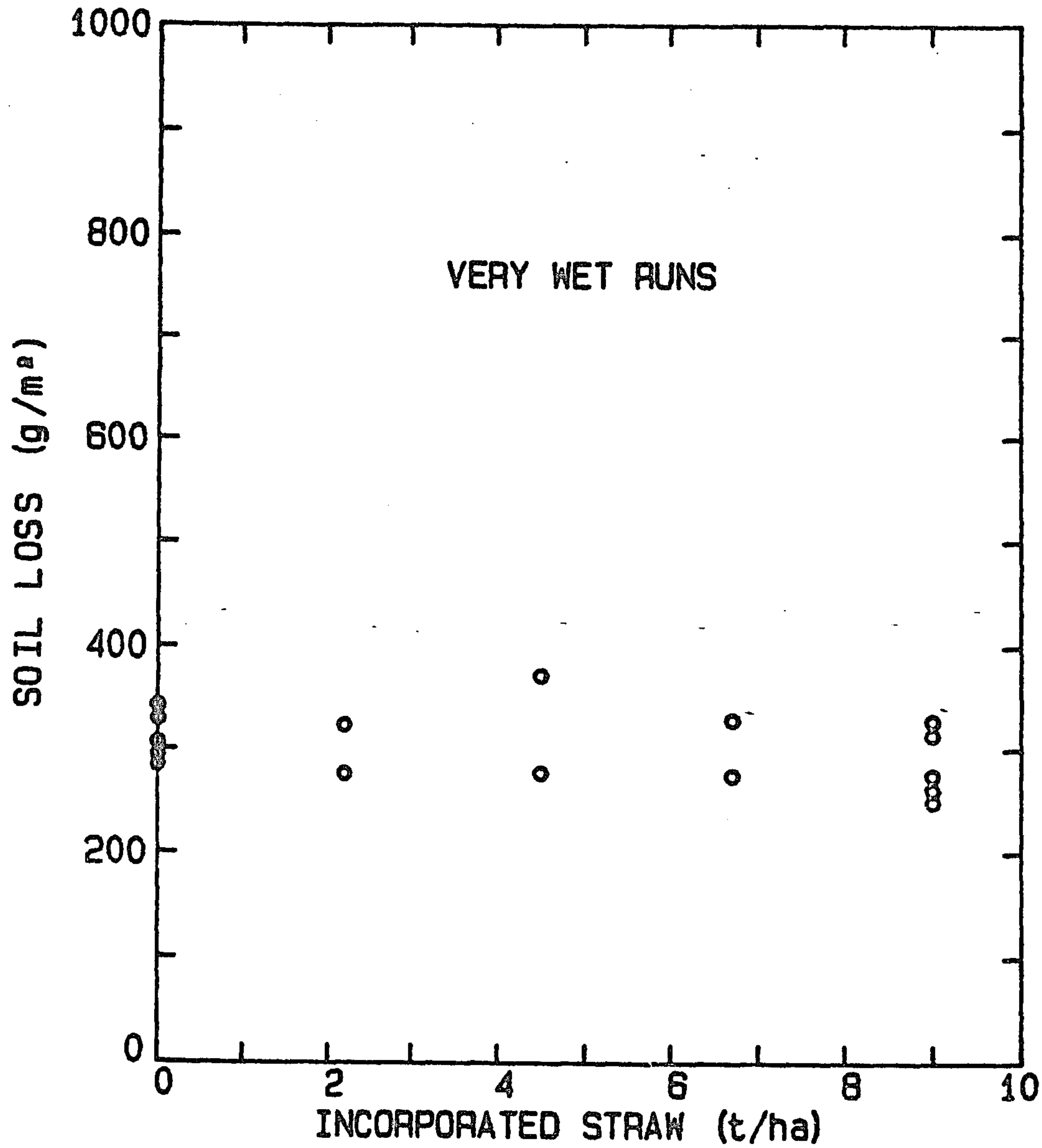

Figure 25. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for very wet runs.

Table 29. Analysis of variance for linear regression of soil loss (g/m^2) from dry runs for incorporated rates of straw of 0, 2.2, 4.5, 6.7 and 9 t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	15	40224			
Incorporated Straw	4	22369	5592	3.45	3.36
Linear Reg.	1	14253	14253	8.78	4.84
Deviation from Linear	3	8116	2705	1.67	3.59
Error	11	17855	1623		

all the soil loss samples during dry runs was 2682, which was only reduced to 1855 with linear regression. Only about 31% of the variation in soil loss was associated with the linear regression on incorporated straw.

Effects of Combinations of Surface Straw and Incorporated Straw on Runoff

A 4 x 2 factorial experiment was used to test the effects of combinations of surface straw and incorporated straw on runoff. Incorporated straw rates were 1, 3, 5 and 7 t/ha, while surface straw rates were 1 and 3 t/ha. A randomized block design was used in which each of the eight treatment combinations was included once in each of three blocks.

Table 30 gives runoff values for the sum of dry, wet and very wet runs for each treatment in each block. Average runoff was 7.99, 7.85, 7.84 and 8.13 cm for incorporated straw rates of 1, 3, 5 and 7 t/ha, respectively, with a surface straw rate of 1 t/ha. Average runoff was 7.80, 7.62, 7.86 and 8.08 cm, respectively, for these same incorporated straw rates with a surface straw rate of 3 t/ha. Table 31 shows no statistical significance on runoff at the 5% level for either the effects of blocking, surface straw rates, incorporated straw rates or the interaction of surface straw rates and incorporated straw rates. Figures 26 and 27 also show the lack of any relationship between runoff and incorporated straw for surface levels of 1 and 3 t/ha, respectively.

Tables 32, 33 and 34 give runoff values for each of three replications for the four levels of incorporated straw over two levels of surface straw for dry, wet and very wet runs, respectively. Table 35 summarizes the average runoff values for each type of run and each

Table 30. Runoff (cm) from the sum of dry, wet, and very wet runs for two rates of surface straw (1, 3 t/ha) and four rates of incorporated straw (1, 3, 5, 7 t/ha).

Surface Straw (t/ha)	Incorporated Straw (t/ha)	Runoff Rep 1 (cm)	Rep 2 (cm)	Rep 3 (cm)	Average (cm)
1	1	7.70	8.53	7.75	7.99
1	3	7.94	7.81	7.81	7.85
1	5	7.70	7.93	7.90	7.84
1	7	8.13	8.15	8.11	8.13
3	1	7.45	8.04	7.92	7.80
3	3	7.71	7.58	7.58	7.62
3	5	8.01	7.87	7.70	7.86
3	7	8.07	8.16	8.01	8.08

Table 31. Analysis of variance for runoff (cm) from dry, wet and very wet runs with surface straw at two levels (1, 3 t/ha) and incorporated straw at four levels (1, 3, 5 and 7 t/ha).

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	23	1.3025			
Blocks	2	0.1466	0.0733	1.72	3.74
Surface Straw	1	0.0771	0.0771	1.81	4.60
Incorporated Straw	3	0.4229	0.1410	3.32	3.34
Sur. x Inc.	3	0.0606	0.0202	0.48	3.34
Error	14	0.5953	0.0425		

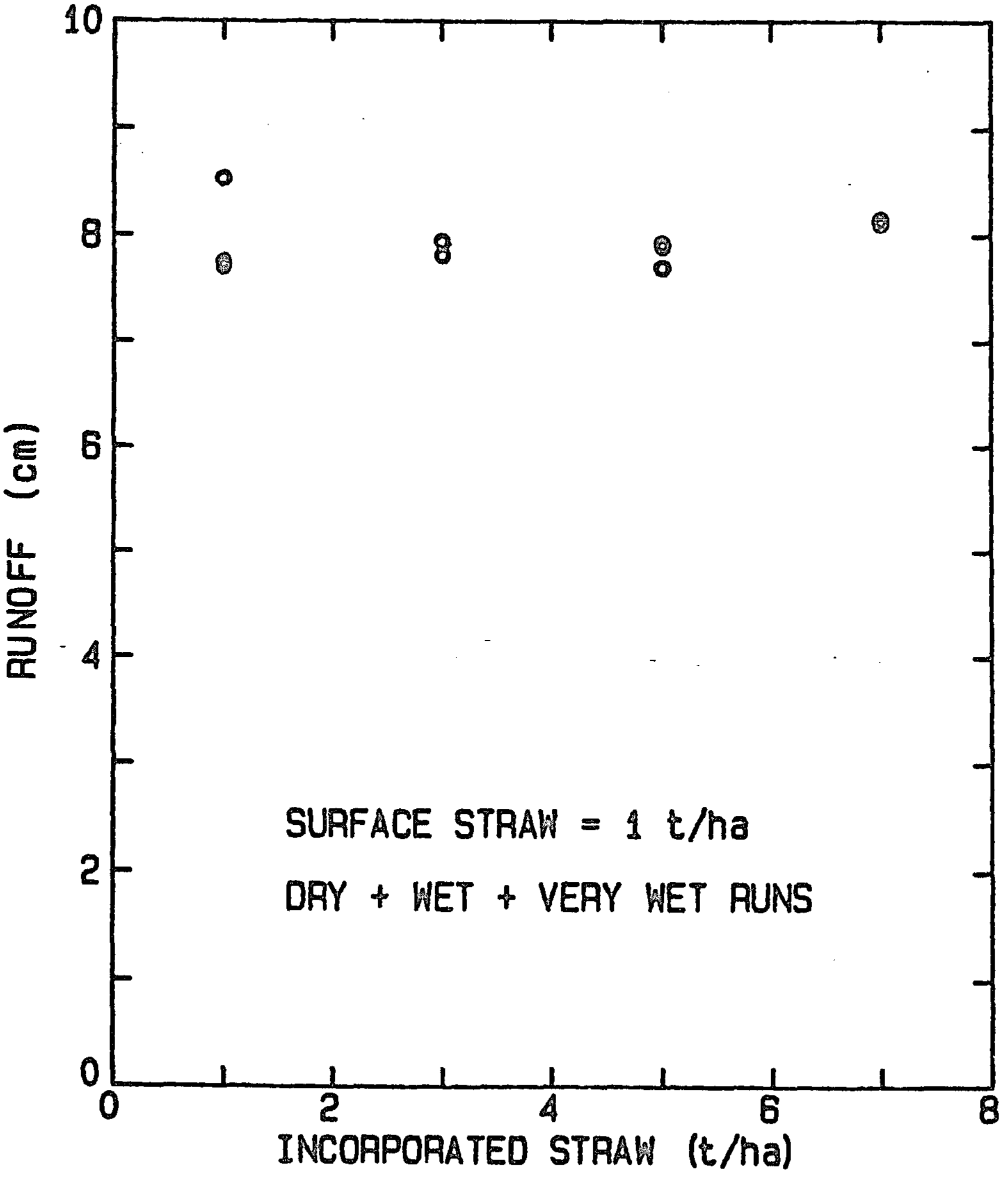

Figure 26. Runoff (cm) plotted versus incorporated straw (t/ha) for the sum of dry, wet and very wet runs and with surface straw of 1 t/ha.

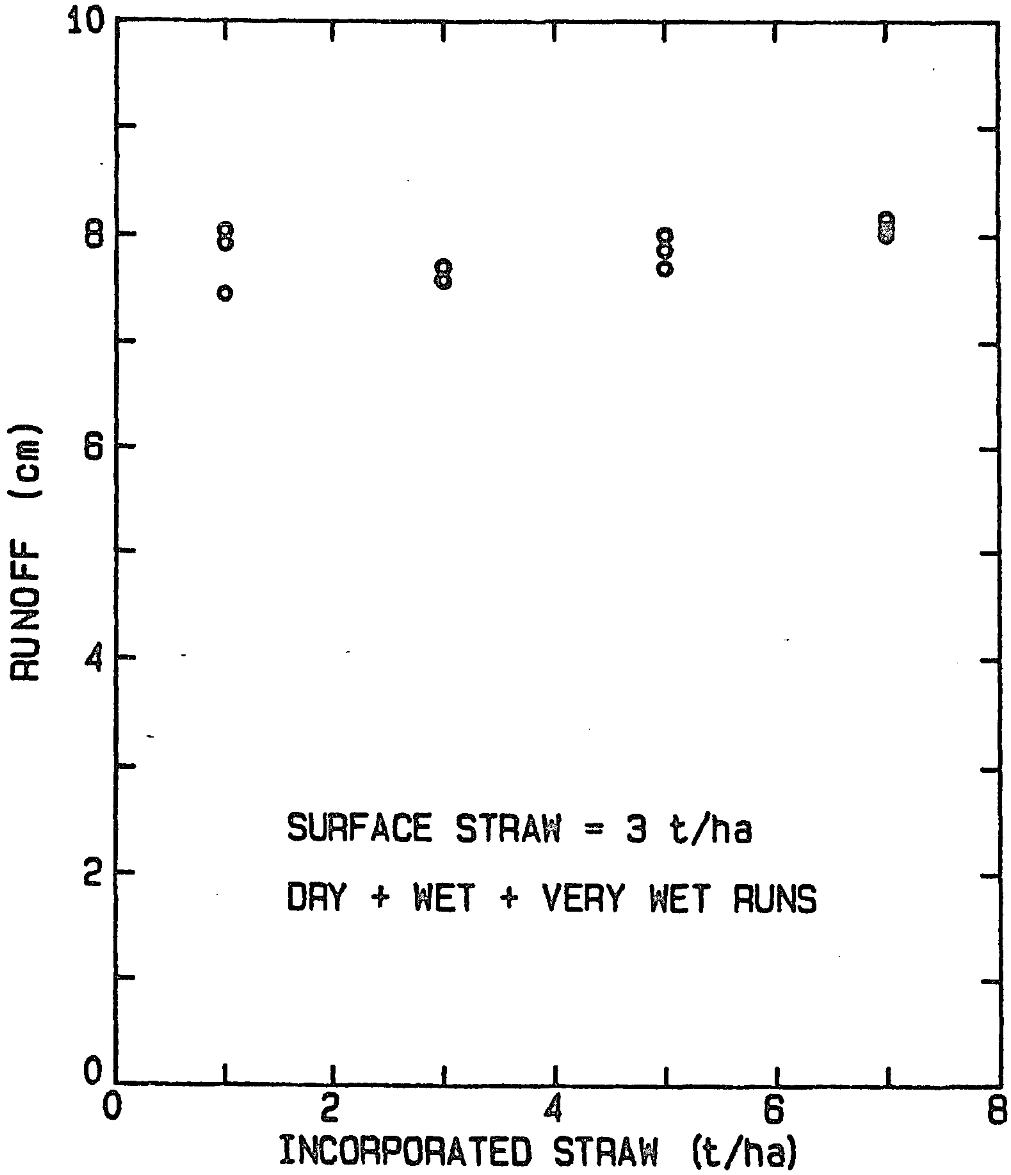

Figure 27. Runoff (cm) plotted versus incorporated straw (t/ha) for the sum of dry, wet and very wet runs and with surface straw of 3 t/ha.

Table 32. Runoff (cm) from dry runs for two rates of surface straw (1, 3 t/ha) and four rates of incorporated straw (1, 3, 5, 7 t/ha).

Surface Straw (t/ha)	Incorporated Straw (t/ha)	Runoff Rep 1 (cm)	Runoff Rep 2 (cm)	Runoff Rep 3 (cm)	Average (cm)
1	1	2.73	3.56	2.72	3.00
1	3	2.89	2.89	2.78	2.85
1	5	2.80	2.96	2.81	2.86
1	7	3.08	3.04	2.86	2.99
3	1	2.44	2.61	2.52	2.52
3	3	2.39	2.56	2.52	2.49
3	5	2.65	2.73	2.45	2.61
3	7	2.77	2.79	2.66	2.74

Table 33. Runoff (cm) from wet runs for two rates of surface straw (1, 3 t/ha) and four rates of incorporated straw (1, 3, 5, 7 t/ha).

Surface Straw (t/ha)	Incorporated Straw (t/ha)	Runoff Rep 1 (cm)	Runoff Rep 2 (cm)	Runoff Rep 3 (cm)	Average (cm)
1	1	2.33	2.29	2.41	2.34
1	3	2.42	2.33	2.46	2.40
1	5	2.30	2.41	2.44	2.38
1	7	2.38	2.44	2.55	2.46
3	1	2.46	2.67	2.70	2.61
3	3	2.60	2.46	2.49	2.52
3	5	2.64	2.53	2.61	2.59
3	7	2.58	2.62	2.65	2.62

Table 34. Runoff (cm) from very wet runs for two rates of surface straw (1, 3 t/ha) and four rates of incorporated straw (1, 3, 5, 7 t/ha).

Surface Straw (t/ha)	Incorporated Straw (t/ha)	Runoff Rep 1 (cm)	Runoff Rep 2 (cm)	Runoff Rep 3 (cm)	Average (cm)
1	1	2.64	2.68	2.62	2.65
1	3	2.63	2.59	2.57	2.60
1	5	2.60	2.56	2.65	2.60
1	7	2.67	2.67	2.70	2.68
3	1	2.55	2.76	2.70	2.67
3	3	2.72	2.56	2.57	2.62
3	5	2.72	2.61	2.64	2.66
3	7	2.72	2.75	2.70	2.72

Table 35. Average runoff (3 replications) from dry, wet and very wet runs for four rates of incorporated straw over two levels of surface straw.

Surface Straw (t/ha)	1				3			
Incorporated Straw (t/ha)	1	3	5	7	1	3	5	7
Average Runoff (cm)								
Dry	3.00	2.85	2.86	2.99	2.52	2.49	2.61	2.74
Wet	2.34	2.40	2.38	2.46	2.61	2.52	2.59	2.62
Very Wet	2.65	2.60	2.60	2.68	2.67	2.62	2.66	2.72

combination of surface and incorporated straw. The average runoff for incorporated rates of straw from 1 and 7 t/ha and with a surface straw rate of 1 t/ha ranged from 2.85 to 3.00, 2.34 to 2.46, and 2.60 to 2.68 cm for dry, wet and very wet runs, respectively. Average runoff for these same rates of incorporated straw but with a surface application of 3 t/ha ranged from 2.49 to 2.74, 2.52 to 2.62, and 2.62 to 2.72 cm for dry, wet and very wet runs, respectively.

An analysis of variance for the dry, wet and very wet runs is presented in Tables 36, 37 and 38, respectively. The effect of surface rates of straw on runoff was significant for the dry and wet runs, but insignificant for the very wet runs. The effect of blocking was significant only for dry runs, but only slightly significant. The effect of incorporated straw on runoff was insignificant for each type of run. Interaction effects between surface and incorporated straw rates were insignificant for each type of run.

Since interaction effects were insignificant and main effects of incorporated straw were insignificant for each type of run, it would be expected that the effects of incorporated straw on runoff over each level of surface straw would also be insignificant for each type of run. Such was the case except for dry runs. The effects of incorporated straw on runoff was slightly significant (Table 39) for dry runs with a surface straw rate of 3 t/ha.

Table 36. Analysis of variance for runoff (cm) from dry runs with surface straw at two levels (1, 3 t/ha) and incorporated straw at four levels (1, 3, 5, 7 t/ha).

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	23	1.4487			
Blocks	2	0.2263	0.1132	4.26	3.74
Surface Straw	1	0.6767	0.6767	25.44	4.60
Incorporated Straw	3	0.1194	0.0398	1.50	3.34
Sur. x Inc.	3	0.0544	0.0181	0.68	3.34
Error	14	0.3719	0.0266		

Table 37. Analysis of variance for runoff (cm) from wet runs with surface straw at two levels (1, 3 t/ha) and incorporated straw at four levels (1, 3, 5, 7 t/ha).

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	23	0.3461			
Blocks	2	0.0281	0.0140	2.86	3.74
Surface Straw	1	0.2109	0.2109	43.04	4.60
Incorporated Straw	3	0.0195	0.0065	1.33	3.34
Sur. x Inc.	3	0.0195	0.0065	1.33	3.34
Error	14	0.0681	0.0049		

Table 38. Analysis of variance for runoff (cm) from very wet runs with surface straw at two levels (1, 3 t/ha) and incorporated straw at four levels (1, 3, 5, 7 t/ha).

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	23	0.0942			
Blocks	2	0.0007	0.0004	0.10	3.74
Surface Straw	1	0.0074	0.0074	1.90	4.60
Incorporated Straw	3	0.0301	0.0100	2.56	3.34
Sur. x Inc.	3	0.0012	0.0004	0.10	3.34
Error	14	0.0548	0.0039		

Table 39. Analysis of variance for runoff (cm) from dry runs with surface straw at one level (3 t/ha) and incorporated straw at four levels (1, 3, 5, 7 t/ha).

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	11	.1937			
Blocks	2	.0413	.0206	3.07	5.14
Incorporated Straw	3	.1120	.0373	5.57	4.76
Linear	1	.0889	.0889	13.27	5.99
Deviation	2	.0231	.0116	1.73	5.14
Error	6	.0404	.0067		

A linear regression of runoff as a function of incorporated straw for dry runs with a surface straw rate of 3 t/ha was significant at the 5% level, with deviations from linear regression being insignificant. The equation was:

$$R.O. = 2.44 + 0.04\ INC.\ ST.$$

with runoff (R.O.) in cm and incorporated straw (INC. ST.) in t/ha. The r^2 for the equation was only 0.46. Although the slope coefficient was very low, a null hypothesis of a slope equal to zero was rejected by use of a two tailed t test. The 95% confidence interval for the slope coefficient was 0.01 to 0.07. Regardless of statistical significance, the above slope factor results in only a very small increase in runoff for the ranges of incorporated straw used in this study.

Mean values of runoff during dry runs for a surface straw rate of 3 t/ha and for incorporated straw rates of 1, 3, 5 and 7 t/ha were 2.52, 2.49, 2.61 and 2.74 cm, respectively. The S.E. of the difference between means, the square root of $(2S^2/3)$, was only 0.067, where S^2 is equal to the error mean square in the analysis of variance. The LSD value was only 0.16 cm, thus the only significant differences between means were the comparisons of 1 versus 7 t/ha and of 3 versus 7 t/ha of incorporated straw. For all practical purposes, these results do not provide sufficient evidence for any effect of incorporated straw on runoff for dry runs. Certainly there was not enough difference from one incorporated straw rate to another to cause any appreciable effect on soil loss.

Figures 28 through 33 show runoff versus incorporated straw for each type of run and for each of the two levels of surface straw. Graphical representation of the data lends visual support for the conclusion in this study of no effect of incorporated straw on runoff.

An unexpected result of this study was the reversal in trends between dry and wet runs for the effect of surface straw on runoff. Runoff during dry runs with a surface rate of 3 t/ha was about 12% less than with surface straw rates of 1 t/ha. During wet runs runoff was 8% higher for the 3 t/ha rate of surface straw than with the 1 t/ha rate.

Table 40 shows the average soil surface moisture contents following dry, wet and very wet runs for the four rates of incorporated straw over two levels of surface straw. Soil surface moisture contents were not affected by increases in incorporated rates of straw over either the 1 or 3 t/ha rate of surface straw; however, the higher surface straw rate generally resulted in slight increases in soil surface moisture contents following runs.

Effects of Combinations of Surface Straw and Incorporated Straw on Soil Loss

A 4 x 2 factorial experiment was used to test the effects of combinations of surface straw and incorporated straw on soil loss. Incorporated straw rates were 1, 3, 5 and 7 t/ha, while surface straw rates were 1 and 3 t/ha. A randomized block design was used in which each of the eight treatment combinations was included once in each of

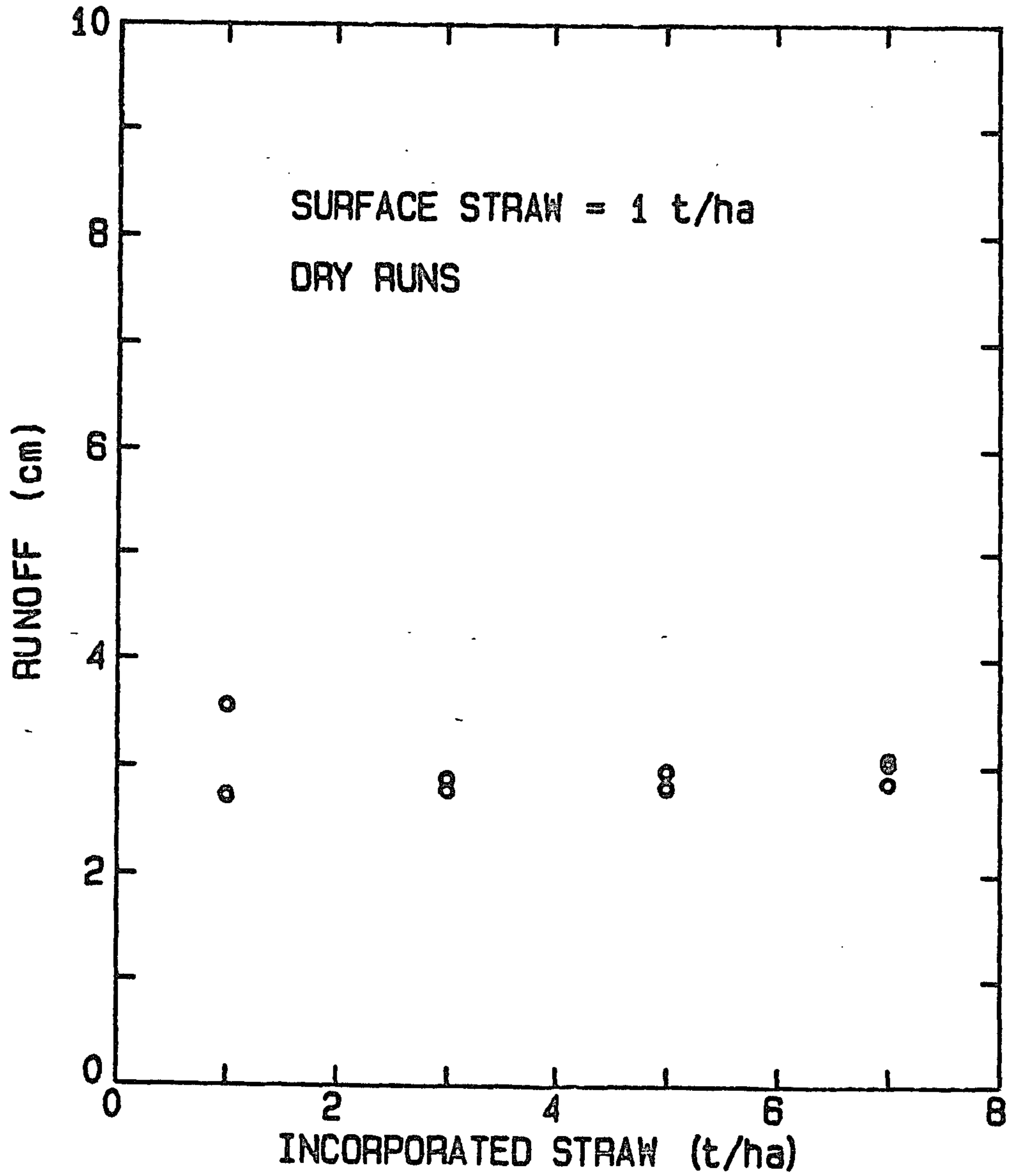

Figure 28. Runoff (cm) plotted versus incorporated straw (t/ha) for dry runs and with surface straw of 1 t/ha.

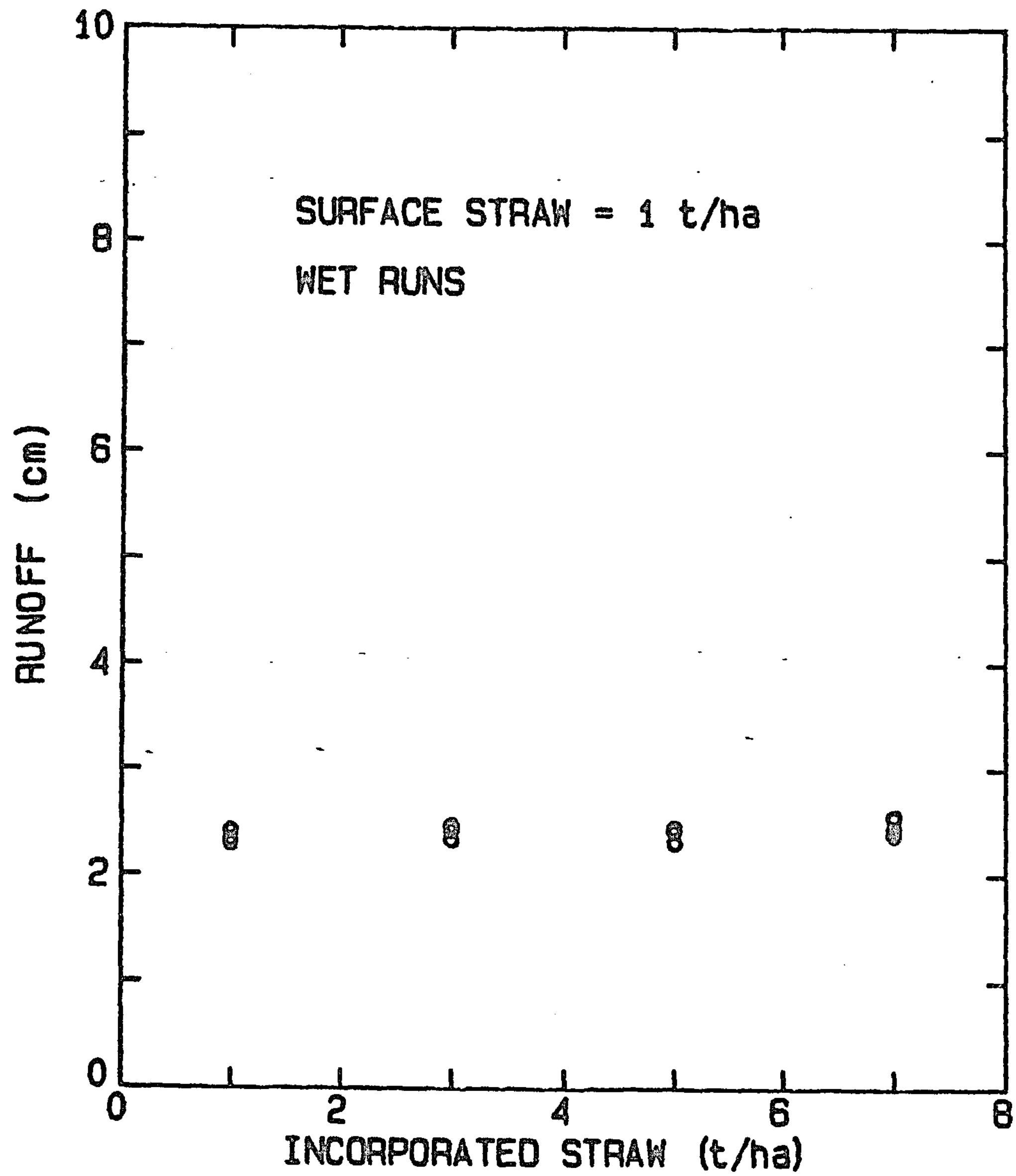

Figure 29. Runoff (cm) plotted versus incorporated straw (t/ha) for wet runs and with surface straw of 1 t/ha.

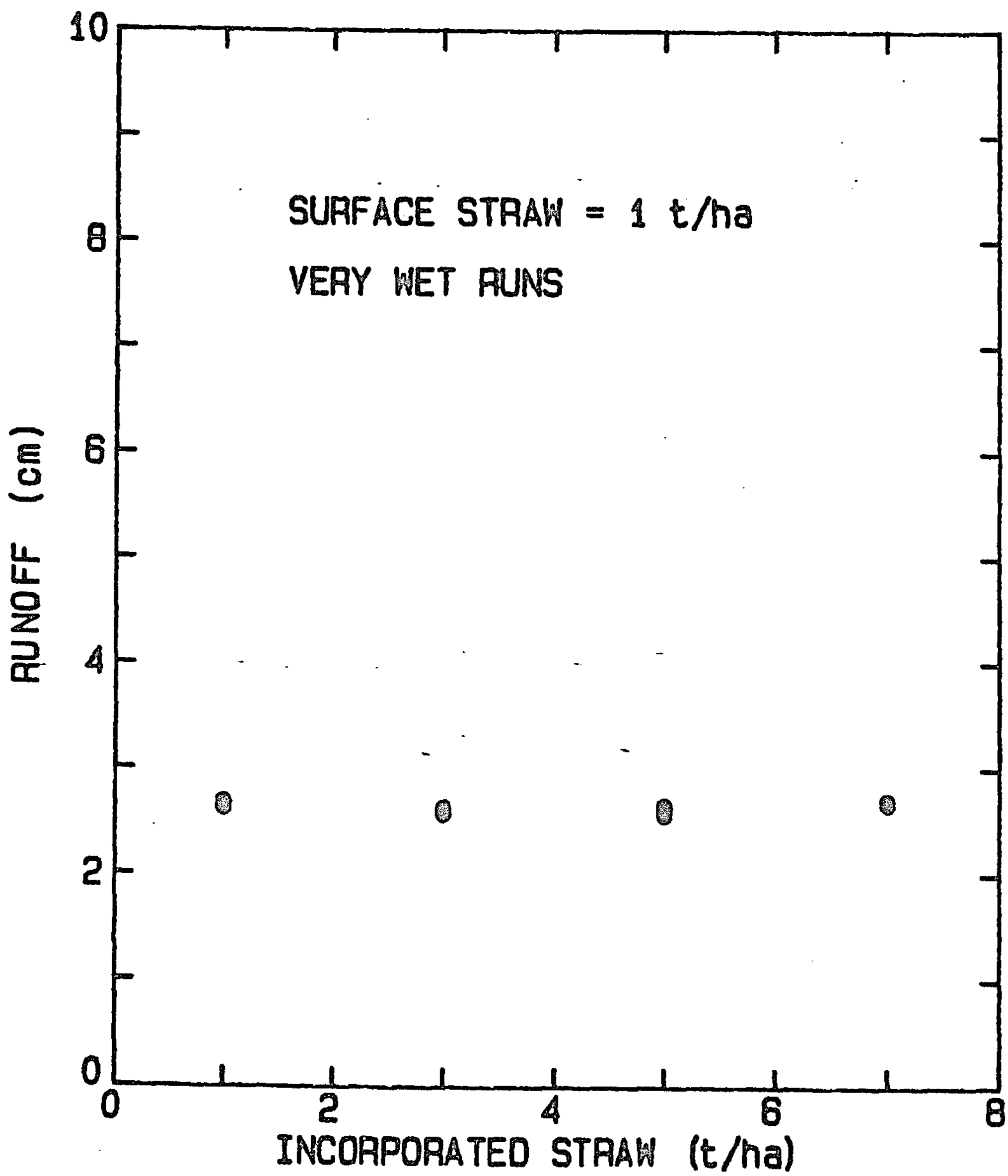

Figure 30. Runoff (cm) plotted versus incorporated straw (t/ha) for very wet runs and with surface straw of 1 t/ha.

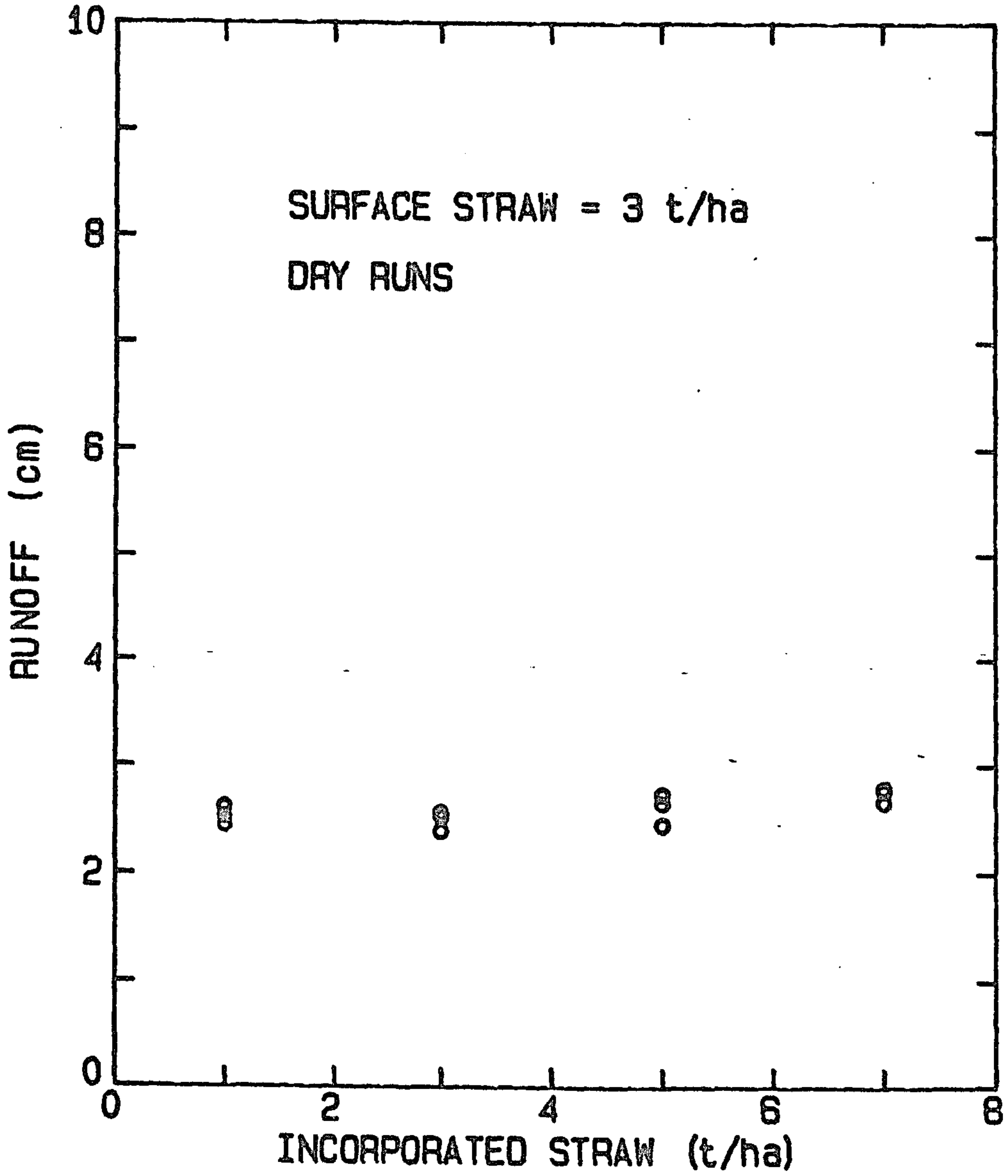

Figure 31. Runoff (cm) plotted versus incorporated straw (t/ha) for dry runs and with surface straw of 3 t/ha.

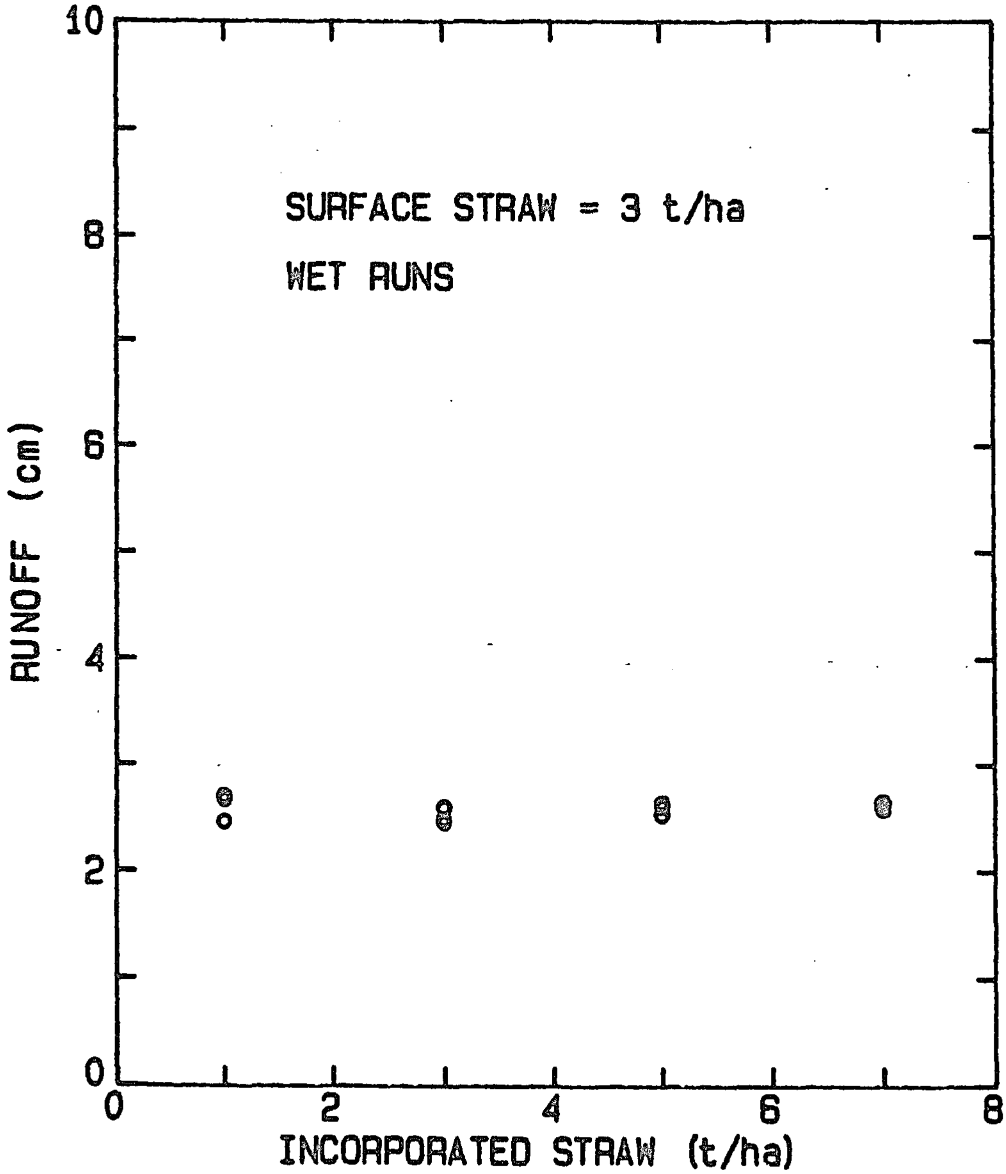

Figure 32. Runoff (cm) plotted versus incorporated straw (t/ha) for wet runs and with surface straw of 3 t/ha.

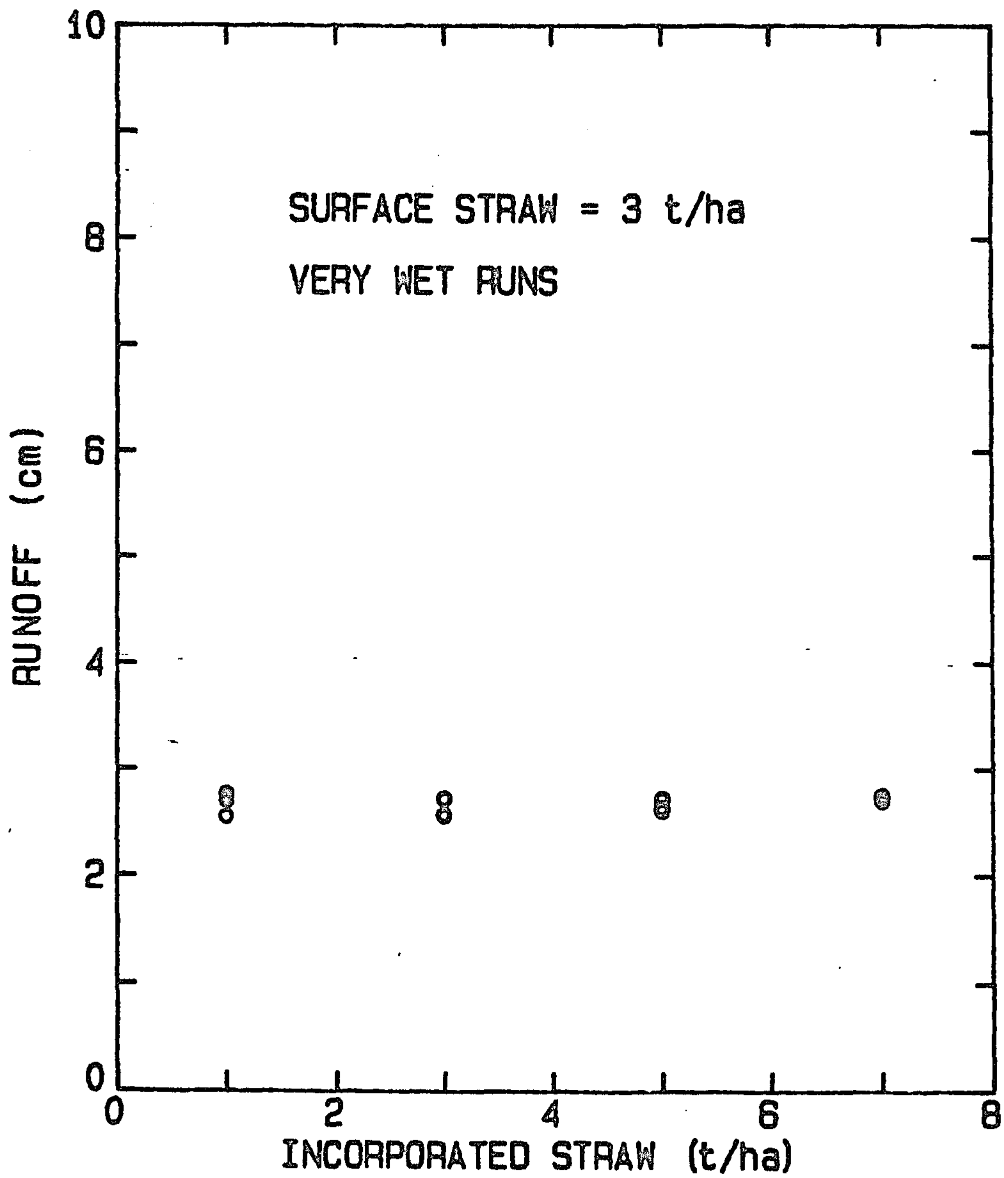

Figure 33. Runoff (cm) plotted versus incorporated straw (t/ha) for very wet runs and with surface straw of 3 t/ha.

Table 40. Average soil surface moisture contents after dry, wet and very wet runs for various rates of incorporated straw with two rates of surface straw.

	AVERAGE SOIL SURFACE MOISTURE CONTENT					
	Surface Straw of 1 t/ha			Surface Straw of 3 t/ha		
Incorporated Straw (t/ha)	After Dry Runs %	After Wet Runs %	After Very Wet Runs %	After Dry Runs %	After Wet Runs %	After Very Wet Runs %
1	31	34	32	35	34	36
3	31	31	31	35	34	36
5	31	32	32	32	34	36
7	30	34	33	34	35	35

three blocks. Table 41 shows soil loss values for the sum of dry, wet, and very wet runs for each treatment in each block.

An analysis of variance (Table 42) shows the effect of incorporated straw on soil loss from the sum of dry, wet and very wet runs was only slightly significant at the 5% level. The effect of surface straw was highly significant. There was no significant interaction. The effect of blocking approached but fell short of significance at the 5% level.

Table 42 subdivides the main effects of incorporated straw into linear, quadratic and cubic components. The quadratic component was slightly significant. Table 43 shows an analysis of variance in which the seven degrees of freedom for the effect of treatments were divided into seven different components, each with one degree of freedom. These included linear, quadratic, and cubic components for incorporated straw for each of the two levels of surface straw, and one component for the effect of surface straw. None of the components for incorporated straw were significant when the surface rate was 3 t/ha, but the linear and quadratic components for incorporated straw were significant for the surface rate of 1 t/ha.

Mean values of soil loss from plots with 1 t/ha of surface straw were 579, 512, 548 and 649 g/m^2 for incorporated rates of 1, 3, 5 and 7 t/ha. Mean values decreased to 293, 281, 281 and 302 g/m^2, respectively, with a surface straw application of 3 t/ha. The standard error (S.E.) of each mean and the S.E. of the difference between two

Table 41. Soil losses (g/m^2) from the sum of dry, wet and very wet runs for two rates of surface straw (1,3 t/ha) and four rates of incorporated straw (1, 3, 5, 7 t/ha).

Surface Straw (t/ha)	Incorporated Straw (t/ha)	Soil Loss (g/m^2)			
		Rep 1 (g/m^2)	Rep 2 (g/m^2)	Rep 3 (g/m^2)	Average (g/m^2)
1	1	553	565	620	579.3
1	3	479	543	515	512.3
1	5	484	509	652	548.3
1	7	587	675	684	648.7
3	1	285	307	286	292.7
3	3	308	275	259	280.7
3	5	258	272	313	281.0
3	7	307	249	350	302.0

Table 42. Analysis of variance for soil loss (g/m^2) from the sum of dry, wet and very wet runs with two rates of surface straw (1, 3 t/ha) and four rates of incorporated straw (1, 3, 4, 7 t/ha).

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	23	547038			
Blocks	2	11389	5694	3.36	3.74
Surface	1	480817	480817	283.67	4.60
Incorporated	3	20681	6894	4.07	3.34
Linear	1	5562	5562	3.28	4.60
Quadratic	1	15050	15050	8.88	4.60
Cubic	1	69	69	0.04	4.60
Sur. x Inc.	3	10421	3474	2.05	3.34
Error	14	23730	1695		

Table 43. Analysis of variance for soil loss (g/m^2) from the sum of dry, wet and very wet runs showing effects of incorporated straw at four levels (1, 3, 5, 7 t/ha) divided into linear, quadratic and cubic components for each level of surface straw (1, 3 t/ha).

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	23	547037.6			
Blocks	2	11389.0	5694	3.36	3.74
Treatments	7	511919.6	73131	43.15	2.77
Inc. L for S1 a/	1	8930.4	8930	5.27	4.60
Inc. Q for S1	1	21000.3	21000	12.39	4.60
Inc. C for S1	1	224.3	224	0.13	4.60
Inc. L for S3	1	120.4	120	0.07	4.60
Inc. Q for S3	1	816.8	817	0.48	4.60
Inc. C for S3	1	10.4	10	0.01	4.60
Surface	1	480817.0	480817	283.67	4.60
Error	14	23729.0	1695		

a/ INC = incorporated straw
L = linear
Q = quadratic
C = cubic
S1 = surface straw at level of 1 t/ha
S3 = surface straw at level of 3 t/ha

means was 23.8 and 33.6 g/m^2, respectively. These S.E. values were computed using the error mean square from the analysis of variance as the variance per individual plot. The 5% level of t (two-tailed with 14 degrees of freedom) times the S.E. of the difference between two means gave a least significant difference of 72.1 g/m^2.

Although the analysis of variance shows slight significance at the 5% level for the effect of incorporated straw on soil loss, examination of the means over both levels of surface straw and visual inspection of the plotted data do not give much support for significance.

None of the means for 1, 3, 5 and 7 t/ha of incorporated straw were significantly different at the 5% level for the 3 t/ha surface straw rate. None of the means for 1, 3 and 5 t/ha were significantly different for a 1 t/ha surface straw rate; however, the mean value of soil loss for 7 t/ha of incorporated straw was significantly different from that at 3 t/ha and also that at 5 t/ha.

Figure 34 shows no evidence of any effect of incorporated straw for a surface rate of 3 t/ha. Figure 35 shows soil loss values for the different rates of incorporated straw with a surface straw rate of 1 t/ha. A 2'nd degree polynomial with soil loss (S.L.) in g/m^2 and incorporated straw (INC. ST.) in t/ha:

$$S.L. = 638.4 - 71.5 \text{ INC. ST.} + 10.5 (\text{INC. ST.})^2$$

was slightly significant at the 5% level (Table 44). A low r^2 of 0.53 indicates a poor fit for the equation. Soil loss predicted

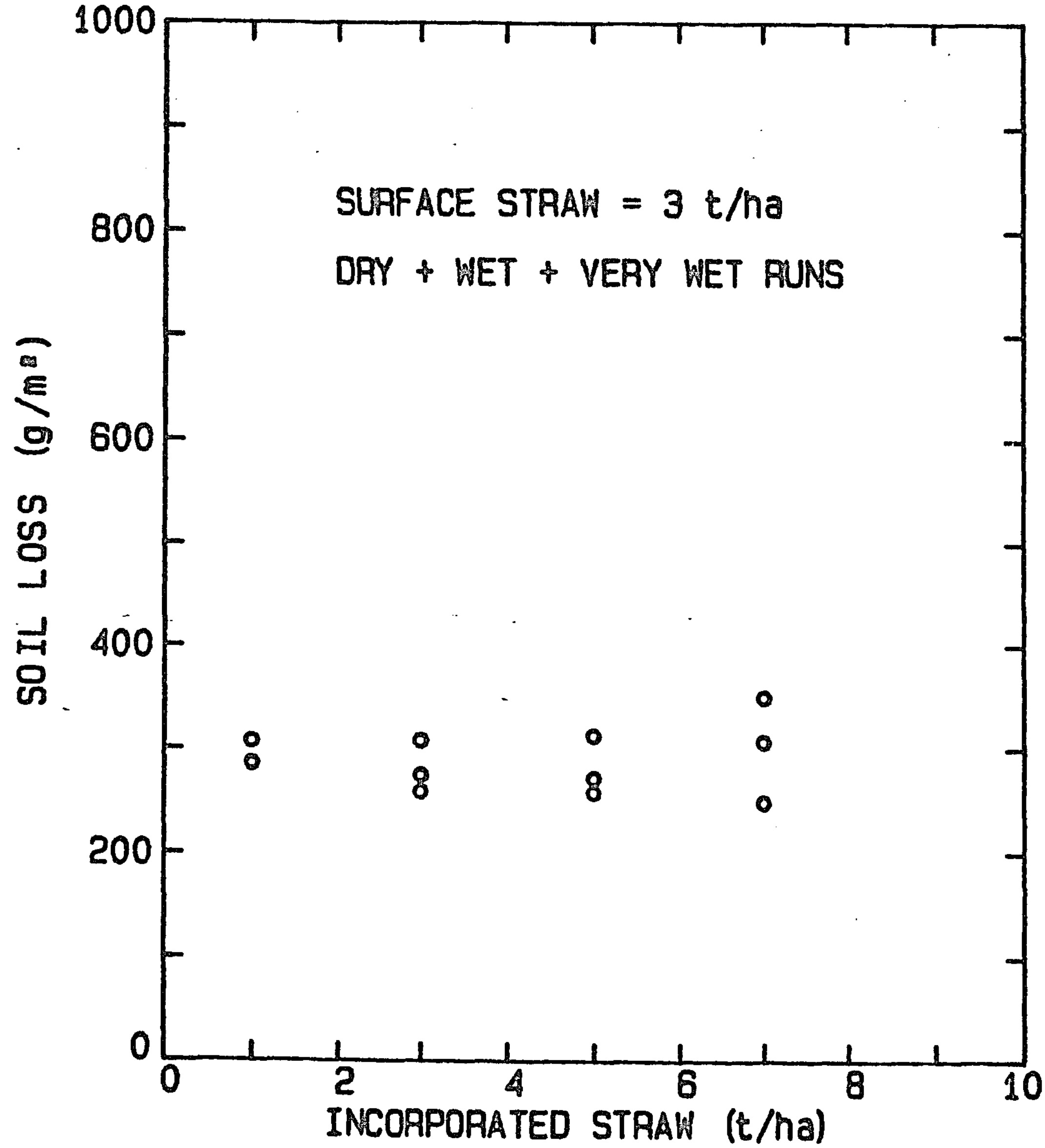

Figure 34. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for the sum of dry, wet and very wet runs and with surface straw of 3 t/ha.

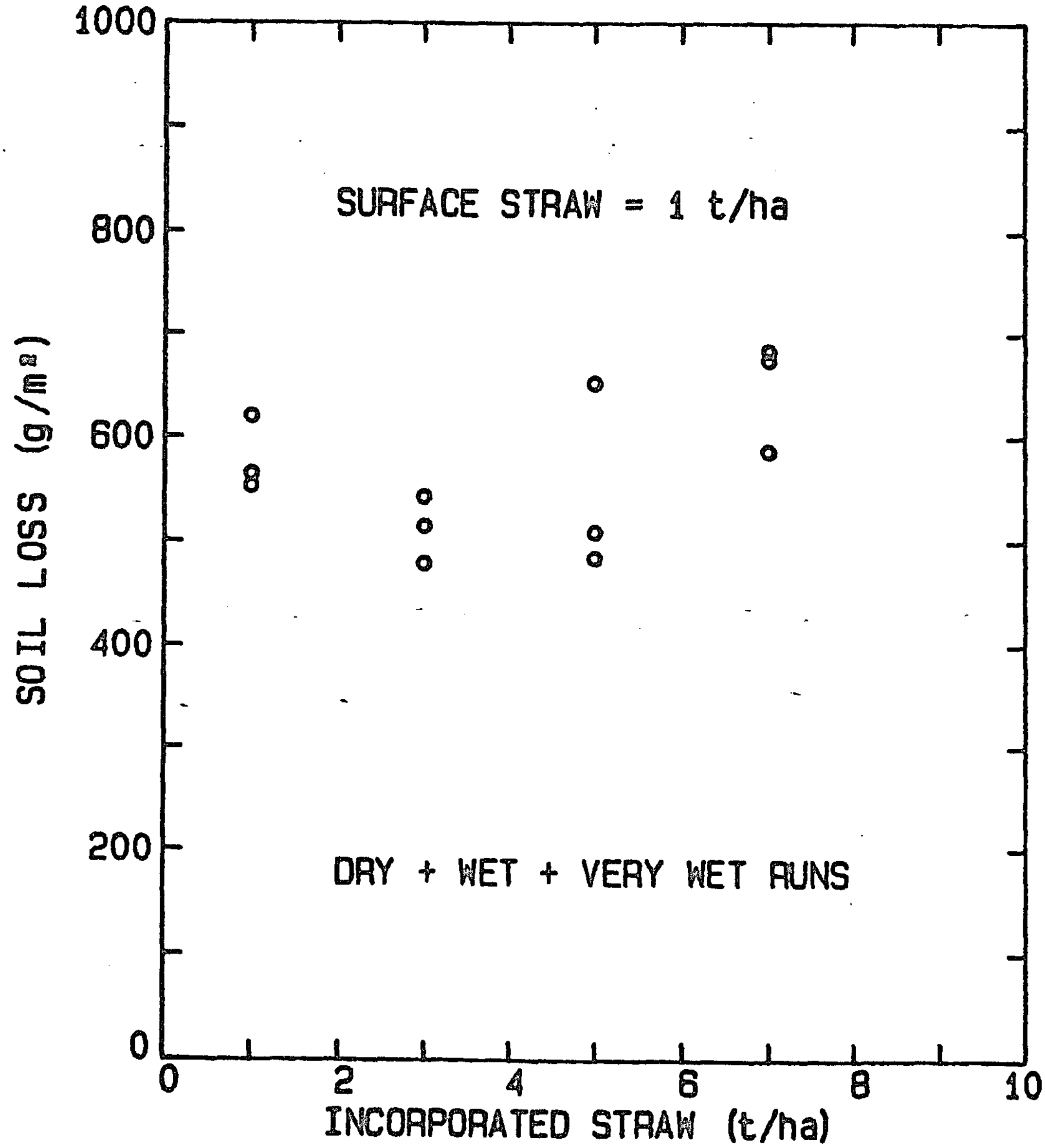

Figure 35. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for the sum of dry, wet and very wet runs and with surface straw of 1 t/ha.

Table 44. Analysis of variance for a quadratic regression of soil loss (g/m^2) from the sum of dry, wet and very wet runs as a function of incorporated straw rates (t/ha) with a surface straw rate of one t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	11	56944			
Quadratic Regression	2	29930	14965	4.99	4.26
Error	9	27014	3002		

by the equation decreases from 577 gm/m^2 at 1 t/ha to a minimum of 517 g/m^2 at 3.4 t/ha and then increased up to 652 g/m^2 at 7 t/ha of incorporated straw. Although the quadratic relationship provided a statistically significant fit to the data, there is no physical basis for this concave type of relationship. Furthermore, as previously stated, none of the means at 1, 3, and 5 t/ha were significantly different, nor was the mean at 1 t/ha significantly different from that at 7 t/ha.

The three samples obtained at each level of incorporated straw over one level of surface straw were probably random samples from populations with means which were not significantly different. In fact, combinations of all samples from 1 through 7 t/ha of incorporated straw for each level of surface straw provided a range of soil loss values for which an hypothesis of a normal distribution could not be rejected, even at the 0.5% level.

A reasonable conclusion is that a case has not been made in this study for any appreciable effect of incorporated straw on soil loss from the sum of dry, wet and very wet runs.

Dry, Wet and Very Wet Runs

Tables 45, 46 and 47 give soil loss values for each of three replications for four levels of incorporated straw (1, 3, 5 and 7 t/ha) over two levels of surface straw (1 and 3 t/ha) for dry, wet and very wet runs, respectively. An analysis of variance (4 x 2 factorial

Table 45. Soil loss (g/m^2) from dry runs for two rates of surface straw (1, 3 t/ha) and four rates of incorporated straw (1, 3, 5, 7 t/ha).

Surface Straw (t/ha)	Incorporated Straw (t/ha)	Soil Loss Rep 1 (g/m^2)	Rep 2 (g/m^2)	Rep 3 (g/m^2)	Average (g/m^2)
1	1	223	254	193	223
1	3	196	219	181	198
1	5	178	212	242	211
1	7	253	272	243	256
3	1	140	120	100	120
3	3	123	130	106	120
3	5	80	122	134	112
3	7	133	101	135	123

Table 46. Soil loss (g/m^2) from wet runs for two rates of surface straw (1, 3 t/ha) and four rates of incorporated straw (1, 3, 5, 7 t/ha).

Surface Straw (t/ha)	Incorporated Straw (t/ha)	Soil Loss (Wet Runs) Rep 1 (g/m^2)	Rep 2 (g/m^2)	Rep 3 (g/m^2)	Average (g/m^2)
1	1	163	145	207	172
1	3	149	162	175	162
1	5	151	157	197	168
1	7	157	199	243	200
3	1	78	105	105	96
3	3	101	73	85	86
3	5	106	78	98	94
3	7	88	73	130	97

Table 47. Soil loss (g/m^2) from very wet runs for two rates of surface straw (1, 3 t/ha) and four rates of incorporated straw (1, 3, 5, 7 t/ha).

Surface Straw (t/ha)	Incorporated Straw (t/ha)	Soil Loss (Very Wet Runs) Rep 1 (g/m^2)	Rep 2 (g/m^2)	Rep 3 (g/m^2)	Average (g/m^2)
1	1	167	166	220	184
1	3	137	162	159	153
1	5	155	140	213	169
1	7	177	204	198	193
3	1	67	82	81	77
3	3	84	72	68	75
3	5	72	72	81	75
3	7	86	75	85	82

design) for soil loss from each of the dry, wet and very wet runs is presented in Tables 48, 49 and 50, respectively.

Effects of incorporated straw and of the interaction of surface and incorporated straw were insignificant for each type of run. The effect of surface straw was significant for each type of run. The effect of blocking was significant only for wet runs and then only slightly significant. Soil loss values in the third block of wet runs were significantly higher than in the first two blocks.

Table 51 shows the average soil loss for each type of run for each combination of surface and incorporated straw, along with S.E. of means, S.E. of the difference between means and LSD values. Ranges of average soil loss values for the four incorporated rates of straw with a rate of 3 t/ha of surface straw were only 112 to 123, 86 to 97, and 75 to 82 g/m^2 for dry, wet and very wet runs, respectively. Obviously, there was no effect of incorporated straw on soil loss with a surface rate of 3 t/ha.

Insignificant effects of incorporated straw with a surface rate of 1 t/ha were not as obvious. In this case, average soil loss values ranged from 198 to 256, 162 to 200, and 153 to 193 g/m^2 for dry, wet and very wet runs, respectively. Omitting the 7 t/ha rate of incorporated straw reduces these ranges to 198 to 223, 162 to 172, and 153 to 184 g/m^2, respectively. According to LSD tests at the 5% level, average soil loss for the 7 t/ha rate of incorporated straw at a level of 1 t/ha of surface straw was significantly greater than the 3

Table 48. Analysis of variance for soil loss (g/m^2) from dry runs for surface straw rates of 1 and 3 t/ha and incorporated straw rates of 1, 3, 5, and 7 t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	23	78337			
Blocks	2	866	433	0.79	3.74
Surface Straw	1	63963	63963	116.72	4.60
Incorporated Straw	3	3517	1172	2.14	3.34
Sur. x Inc.	3	2315	772	1.41	3.34
Error	14	7676	548		

Table 49. Analysis of variance for soil loss (g/m^2) from wet runs for surface straw rates of 1 and 3 t/ha and incorporated straw rates of 1, 3, 5, and 7 t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	23	53498			
Blocks	2	5105	2552	6.79	3.74
Surface Straw	1	40426	40426	107.52	4.60
Incorporated Straw	3	1858	619	1.65	3.34
Sur. x Inc.	3	849	283	0.75	3.34
Error	14	5260	376		

Table 50. Analysis of variance for soil loss (g/m^2) from very wet runs for surface straw rates of 1 and 3 t/ha and incorporated straw rates of 1, 3, 5, and 7 t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	23	66323			
Blocks	2	1825	912	3.01	3.74
Surface Straw	1	57330	57330	189.21	4.60
Incorporated Straw	3	1916	639	2.11	3.34
Sur. x Inc.	3	1013	338	1.12	3.34
Error	14	4238	303		

Table 51. Average soil loss (3 replications) from dry, wet and very wet runs for four rates of incorporated straw over two levels of surface straw.

Surface Straw (t/ha)	1				3			
Incorporated Straw (t/ha)	1	3	5	7	1	3	5	7
Average [a/] Soil Loss (g/m^2)								
Dry	223	198	211	256	120	120	112	123
Wet	172	162	168	200	96	86	94	97
Very Wet	184	153	169	193	77	75	75	82

(a) Standard errors of means were 13.5, 11.2, and 10.0 g/m^2 for dry, wet and very wet runs, respectively.

Standard errors of the difference between two means were 19.1, 15.8, and 14.2 g/m^2 for dry, wet and very wet runs, respectively.

Least significant differences between means were 41.0, 34.0, and 30.5 g/m^2 for dry, wet and very wet runs, respectively, at the 5% level of significance.

and 5, 3, and 3 t/ha incorporated rates in the dry, wet and very wet runs, respectively.

Soil loss versus incorporated rates of straw for each type of run and for each level of surface straw are shown in Figures 36 through 41. In general, there was no relationship between rates of incorporated straw and soil loss for either level of surface straw. A statistically significant fit was obtained for the dry runs for a surface straw rate of 1 t/ha as follows:

$$S.L. = 248.5 - 30.0\ (INC.\ ST.) + 4.4\ (INC.\ ST.)^2$$

where soil loss (S.L.) is in g/m^2 and incorporated straw (INC. ST.) is in t/ha. The r^2 was only 0.52. The analysis of variance for this regression equation (Table 52) shows that the fit was only slightly signficant at the 5% level. The equation does not describe any physical effect on soil loss due to incorporated straw.

Results from this study indicate that varying rates of incorporated straw had no effect on soil loss from either dry, wet or very wet runs. A slightly significant regression, which had no physical basis, was found for soil loss as a function of incorporated straw with a surface straw rate of 1 t/ha during dry runs. However, no significant regression was obtained for dry runs with a surface rate of 3 t/ha, and no significant regressions were found for wet or very wet runs over either level of surface straw.

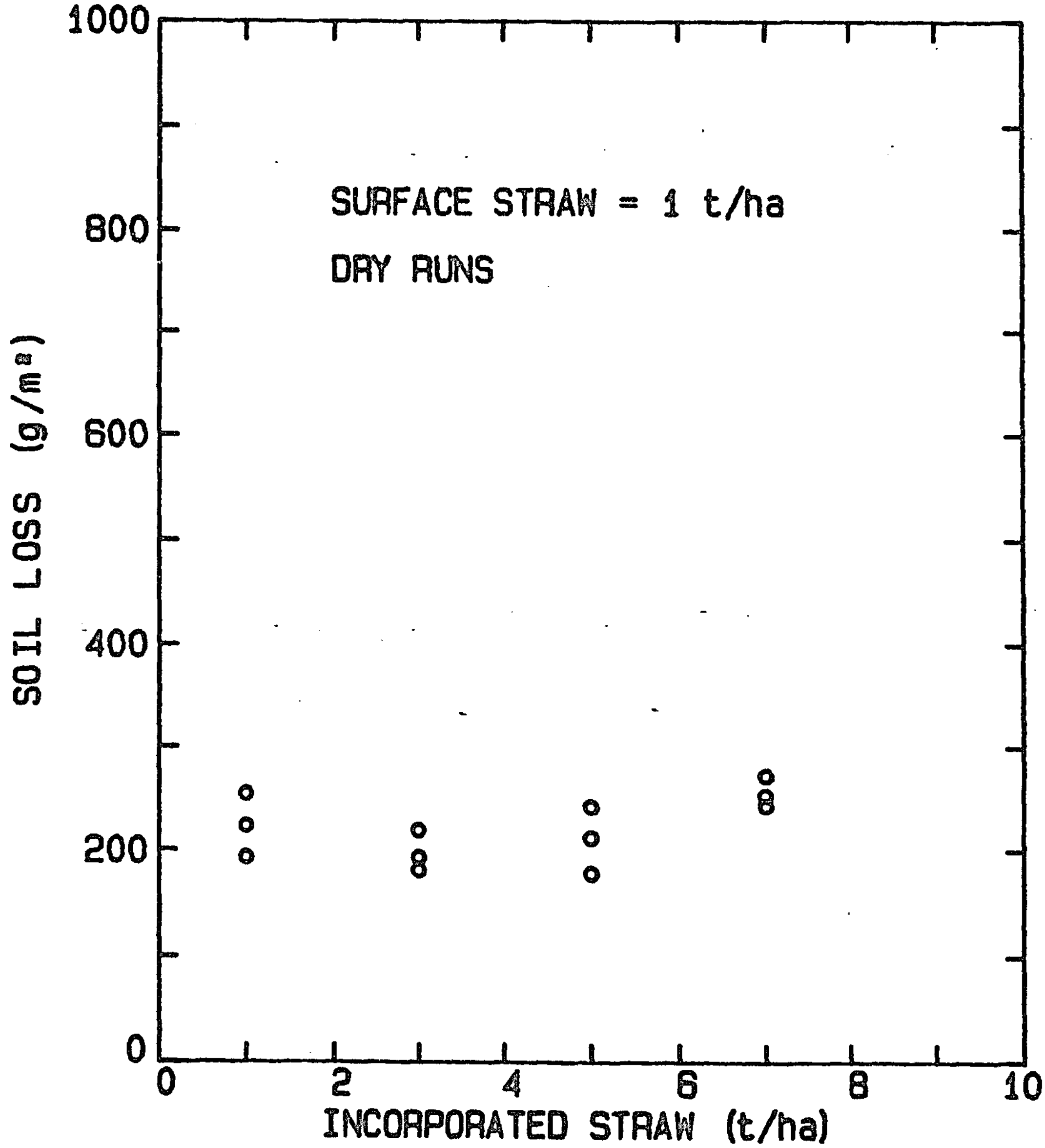

Figure 36. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for dry runs and with surface straw 1 t/ha.

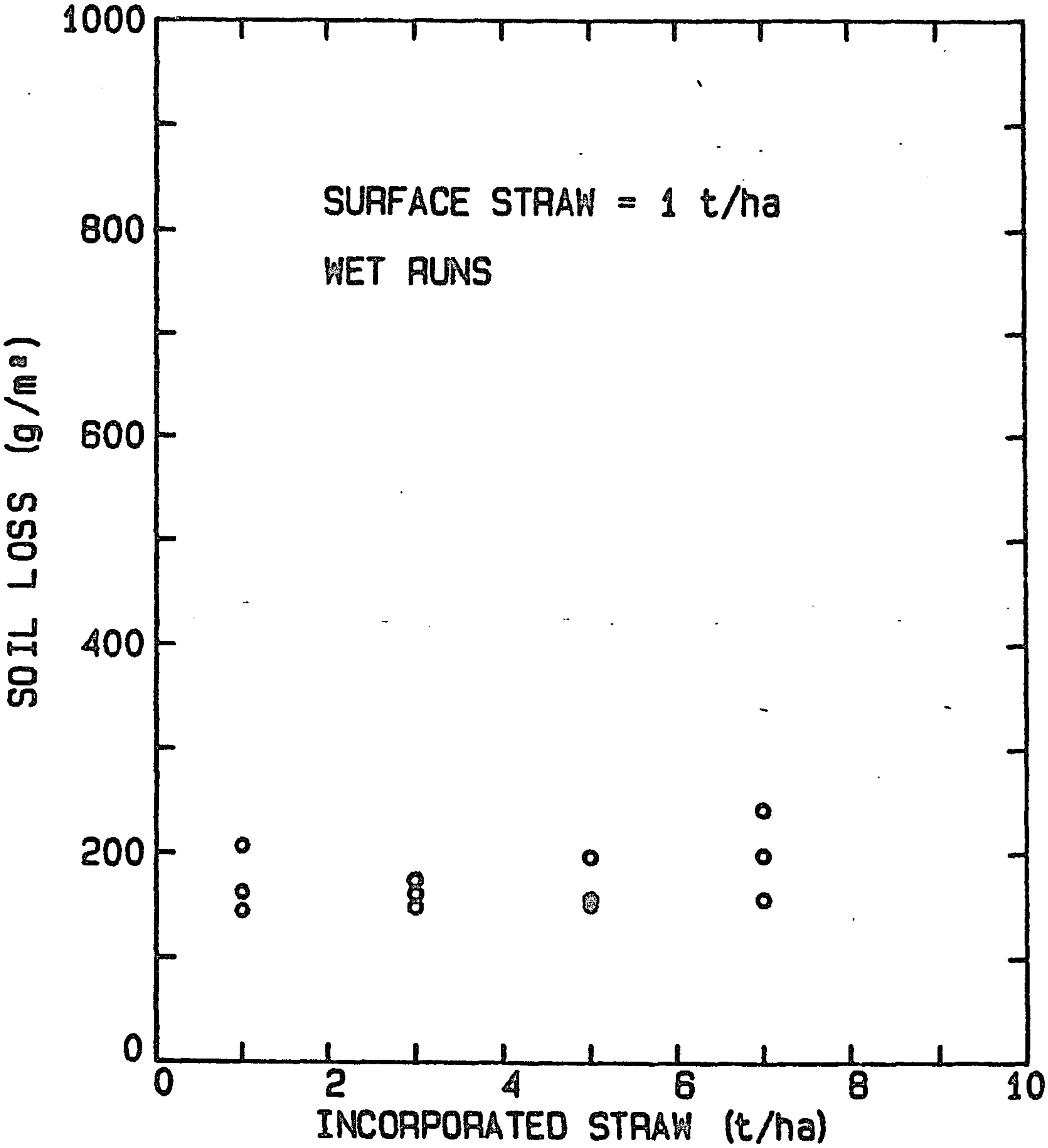

Figure 37. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for wet runs and with surface straw 1 t/ha.

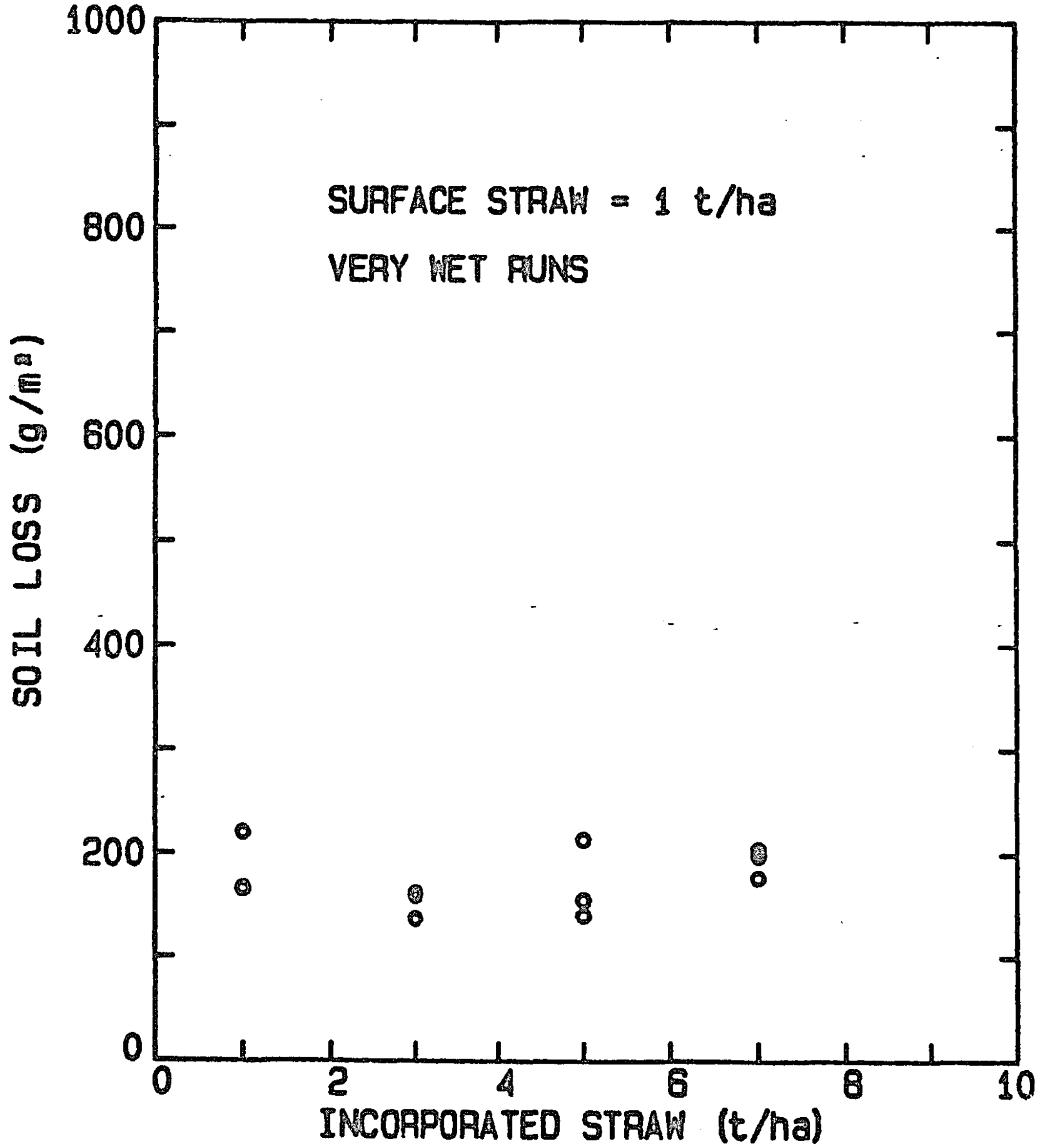

Figure 38. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for very wet runs and with surface straw of 1 t/ha.

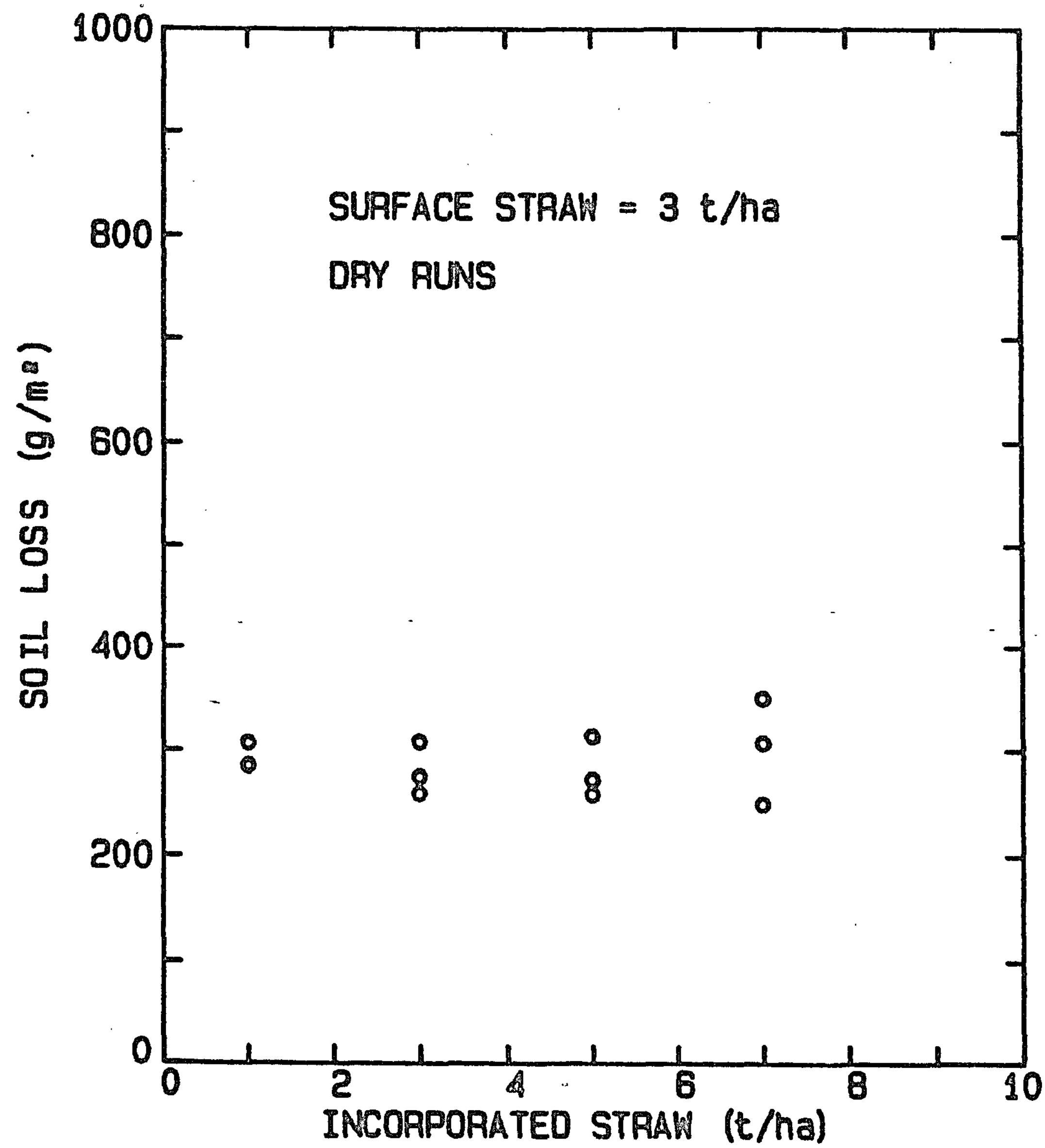

Figure 39. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for dry runs and with surface straw of 3 t/ha.

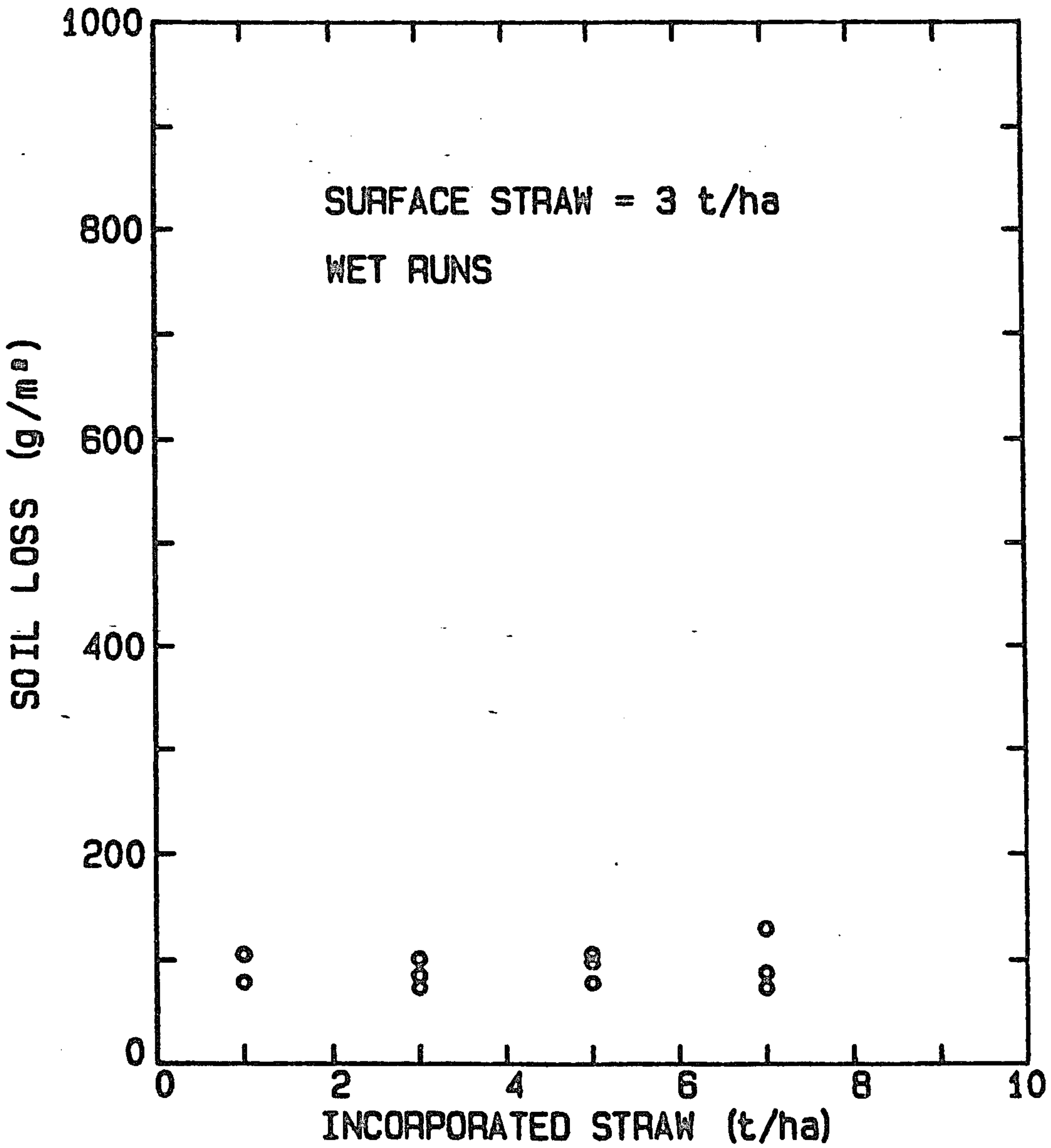

Figure 40. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for wet runs and with surface straw of 3 t/ha.

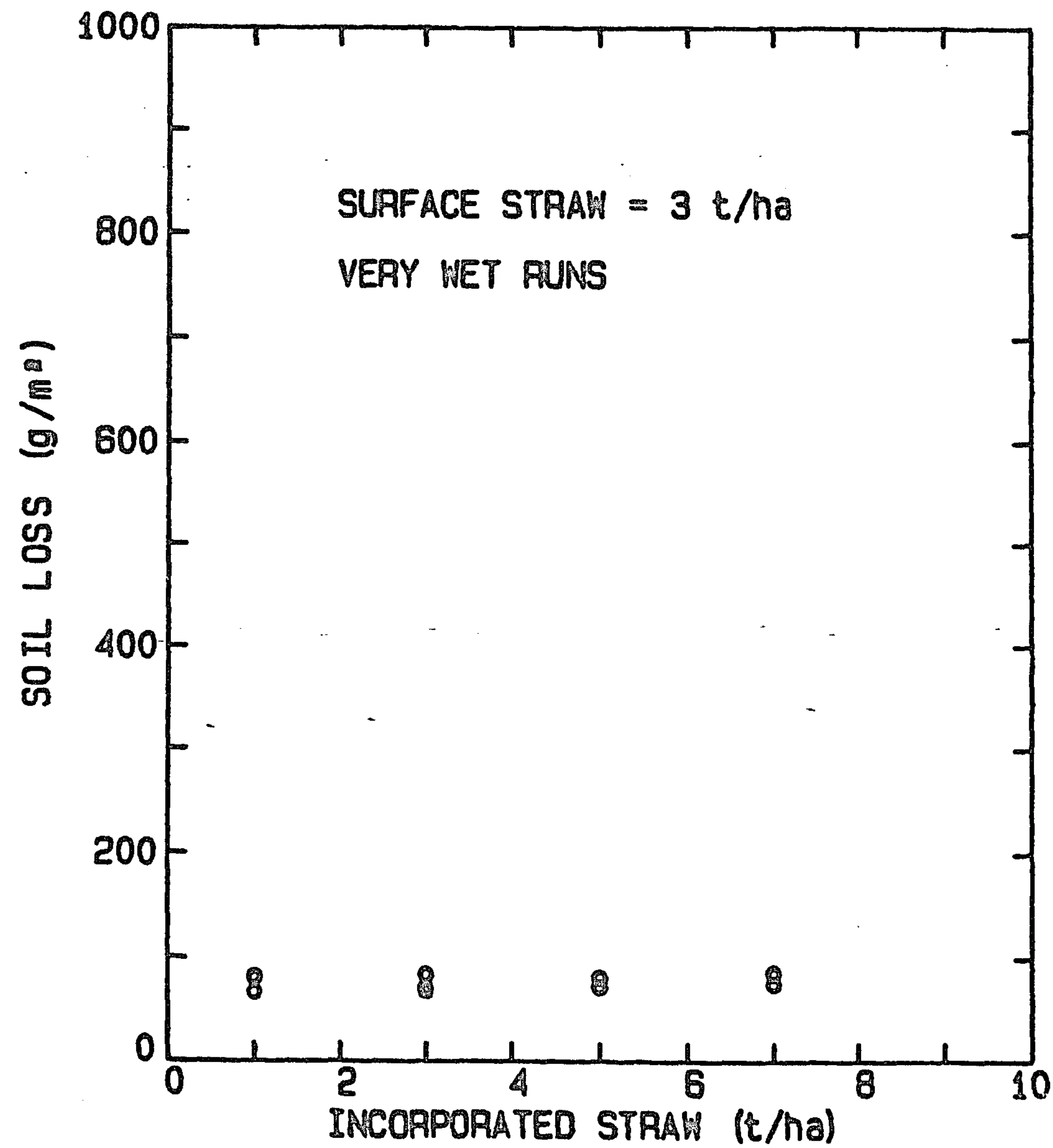

Figure 41. Soil loss (g/m^2) plotted versus incorporated straw (t/ha) for very wet runs and with surface straw of 3 t/ha.

Table 52. Analysis of variance for a quadratic regression of soil loss (g/m^2) from dry runs as a function of incorporated straw rates (t/ha) with a surface rate of one t/ha.

Analysis of Variance

Source	Degree of Freedom	Sum of Squares	Mean Square	F	$F_{(.05)}$
Total	11	10735			
Quadratic Regression	2	5629	2814	4.96	4.26
Error	9	5106	567		

SUMMARY

The erosion process begins when raindrops strike the soil surface. Raindrops dislodge soil particles and runoff entrains and transports the detached soil material. Erosion of farmland is reduced the most by cropping systems that minimize soil disturbance at planting and during the early growing season of crops while also maintaining maximum levels of surface cover throughout the year. Surface cover can be provided by crop canopy and by crop residues. No-till farming, however, is not feasible everywhere. Answers are needed concerning the erosion control benefits of partially and fully incorporating various rates of crop residues into the soil.

This study was conducted to determine the effects of interrill erosion and runoff on a Grenada silt loam soil for: (1) various rates of surface straw, (2) various rates of incorporated straw, and (3) various rates of incorporated straw over two levels of surface straw. The procedure involved placement of air-dried Grenada silt loam soil into a 0.91 by 0.91-m soil pan on 2.5% slope with a central test area of 0.46 by 0.46-m. Simulated rainfall of 64 mm/hr was applied for a 60-minute dry run and for two 30-minute wet and very wet runs for each of the surface straw, incorporated straw, and combined surface and incorporated straw treatments.

The various rates of surface straw had little effect on total runoff from the combined dry, wet and very wet runs. Runoff slightly increased with increasing rates of straw up to 2 t/ha and then only

slightly decreased with further additions of straw. Statistically significant regressions relating runoff (cm) with surface straw (t/ha) were obtained for the combined runs and for each separate run, but the small numerical differences in runoff for different rates of straw could not account for any appreciable difference in soil loss.

Increasing rates of surface straw (0, 0.5, 1, 2, 4, 6 and 8 t/ha) resulted in decreased rates of soil loss. Total soil loss (g/m^2) from the combined dry, wet, and very wet runs decreased with increasing rates of surface straw (t/ha) as follows:

$$\text{Ln (S.L.)} = 6.66 - 0.302 \text{ (ST)}$$

Soil loss (g/m^2) decreased as a function of increasing surface straw rates (t/ha) for the dry, wet and very wet runs as follows:

Dry $\quad \text{Ln (S.L.)} = 5.63 - 0.334 \text{ (ST)}$

Wet $\quad \text{Ln (S.L.)} = 5.46 - 0.258 \text{ (ST)}$

Very Wet $\quad \text{Ln (S.L.)} = 5.59 - 0.323 \text{ (ST)}$

Soil losses from the combined wet and very wet periods were compared with that from the dry period, giving a comparison of two 60-minute periods with very different initial moisture contents. The ratio of soil loss for the 60-minute period using the combined wet and very wet runs as compared to the 60-minute dry run increased from 1.8 to 2.3 for surface straw rates from 0 to 8 t/ha. Numerical differences in soil loss for the two periods decreased from 224 g/m^2 for 0 t/ha of surface straw to only 28 g/m^2 for 8 t/ha of surface straw. The equation for soil loss (g/m^2) as a function of surface straw (t/ha) for the combined wet and very wet runs was:

$$Ln\ (S.L.) = 6.22 - 0.29\ (ST)$$

An analysis of variance showed that the effect of incorporated straw (0, 2.2, 4.5, 6.7 and 9 t/ha) on total soil loss from combined dry, wet and very wet runs was not significant. An analysis of variance for each of the separate runs showed that the effect of incorporated straw on soil loss was insignificant for wet and very wet runs and just reached significance at the 5% level for dry runs. Even during dry runs the mean values of soil loss were not significantly different for rates of 2.2 through 9.0 t/ha of incorporated straw. There was insufficient evidence to conclude any effect of incorporated straw on either runoff or soil loss.

There was also insufficient evidence to conclude that runoff was affected by increasing rates of incorporated straw for different levels of surface straw. The factorial analysis of variance for the sum of rainulator values from dry, wet and very wet runs showed no statistical significance at the 5% level for either the effects of incorporated straw rates or the interaction of surface straw rates and incorporated straw rates. A factorial analysis for each individual type of run (dry, wet and very wet) also resulted in insignificant effects of increasing rates of incorporated straw on runoff over two levels of surface straw. Significance for the effect of incorporated straw on runoff was just reached at the 5% level for dry runs for a surface straw rate of 3 t/ha; however, the correlation coefficient for the resulting linear equation was only 0.46. The mean values of runoff during dry runs for incorporated straw rates of 1, 3, 5 and 7 t/ha were 2.52, 2.49, 2.61 and 2.74 cm, respectively. Differences in these mean values are not large enough to cause any appreciable differences in soil loss.

There was insufficient evidence to conclude that incorporated straw rates (1, 3, 5 and 7 t/ha) over two levels of surface straw (1 and 3 t/ha) had any effect on soil loss for the combined dry, wet and very wet runs. The factorial analysis of variance did show that significance was just reached at the 5% level; however, examination of the effects of incorporated straw on soil loss at the individual levels of surface straw indicated insignificance for the surface rate of 3 t/ha. Furthermore, none of the mean values of soil loss for incorporated rates of 1, 3, and 5 t/ha were significantly different when there was a surface rate of 1 t/ha, and mean values of soil loss for the 1 and 7 t/ha rate of incorporated straw were not significantly different. A quadratic relationship between soil loss (g/m^2) and incorporated straw rates (t/ha) for the surface straw rate of 1 t/ha resulted in a statistically significant fit to the data, but the concave shape of the curve had no physical basis. A separate analysis of variance for each type of run (dry, wet and very wet) did not result in any significant effects of incorporated straw on soil loss for either level of surface straw.

Results of this study agreed in several aspects with many of those discussed in the review of literature. Additions of surface straw were very effective in reducing soil loss, thus agreeing with results reported by Harmon and Meyer (1978), Kramer and Meyer (1969), Lattanzi et al. (1974) and Lang et al. (1984). The formation of a surface seal under raindrop impact had also been noted by other researchers, including Edwards (1976), Lang et al. (1984) and Meyer and Mannering (1967).

Small changes in runoff with different levels of surface straw under simulated rainfall agreed with laboratory results for surface straw rates up to 2 t/ha by Harmon and Meyer (1978) and Lattanzi et al. (1974), and with field plot results by Meyer et al. (1970) for surface straw rates up to 9 t/ha. Harmon and Meyer (1978) and Lattanzi et al. (1974) did note reductions in runoff for high rates of surface straw in their laboratory experiments. Mannering and Meyer (1963) also reported reductions in runoff for increasing rates of surface straw for field plot experiments under simulated rainfall. Dissimilar runoff results but similar soil loss trends for increasing rates of surface residues for the different studies indicated that a major contribution of surface residues in reducing interrill soil erosion was the protection of soil from raindrop impact.

A major contribution of this study was the finding that incorporated straw had essentially no effect on interrill soil erosion of Grenada silt loam soil. This result was attributed to the surface sealing of the Grenada silt loam soil.

Information obtained from this study of the effects of straw residues on soil erosion adds to the store of basic knowledge about the effects of residue placement on soil erosion. Erosion data from this study and from similar laboratory experiments are useful to other researchers in designing field experiments concerning the effects of residue placement on soil erosion. Results of this study dealing with the effects of surface residues can be particularly useful to those concerned with the development and improvement of models that deal with the interrill aspect of soil erosion.

CONCLUSIONS

Major conclusions of this study as applied to Grenada silt loam soil on a 2.5% slope with simulated rainfall of 64 mm/hr and considering only the interrill aspects of the erosion process are:

1. Applications of surface straw from 0 to 8 t/ha resulted in an exponential decrease in soil loss for the sum of dry, wet and very wet runs and also for each dry, wet, or very wet run.

2. The decrease in soil loss for increasing rates of surface straw was not due to any decrease in runoff. In fact, there was little change in runoff for increasing rates of surface straw, indicating less detached soil material was available for transport.

3. Increasing rates of surface straw resulted in less soil loss because the increased cover provided increased protection of the soil surface from the impact of raindrops.

4. The effect on runoff of increasing rates of incorporated straw from 0 to 9 t/ha with zero levels of surface straw was insignificant at the 5% level for the sum of dry, wet, and very wet runs, and also for the individual wet runs.

5. There was not enough evidence to conclude any effect on runoff from dry or very wet runs for increasing rates of incorporated straw from 0 to 9 t/ha with zero levels of surface straw.

6. Increasing rates of incorporated straw from 0 to 9 t/ha with zero levels of surface straw did not result in significant changes in the sum of soil losses from dry, wet and very wet runs or for the individual wet and very wet runs.

7. There was not enough evidence to conclude any effect on soil loss from dry runs caused by increasing rates of incorporated straw from 0 to 9 t/ha with zero levels of surface straw.

8. Increasing rates of incorporated straw from 1 to 7 t/ha with surface straw of 1 or 3 t/ha had an insignificant effect at the 5% level on the sum of runoff from dry, wet or very wet runs and on runoff from individual wet or very wet runs.

9. Increasing rates of incorporated straw from 1 to 7 t/ha with surface straw of 1 t/ha had an insignificant effect at the 5% level on runoff from dry runs, and there was insufficient evidence to conclude any effect on runoff of incorporated straw for dry runs when there was surface straw of 3 t/ha.

10. Increasing rates of incorporated straw from 1 to 7 t/ha with a surface rate of 3 t/ha had no effect at the 5% level on the sum of soil losses from dry, wet and very wet runs or for individual dry, wet or very wet runs.

11. Increasing rates of incorporated straw from 1 to 7 t/ha with a surface straw of 1 t/ha had an insignificant effect at the 5% level on soil loss from either dry, wet or very wet runs; and

there was insufficient evidence to conclude any effect on the sum of soil losses from dry, wet and very wet runs.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. Determine the effect of incorporated straw with and without surface straw on rill erosion of Grenada silt loam soil to complement this study involving interrill erosion.

2. Determine the validity of the assumption that equal amounts of soil and water are splashed into and out of the central test area of the soil pan. Results of the study showed slightly but consistently higher runoff rates for increases of surface straw from 0 to 1 or 2 t/ha. These results could possibly have been caused by less material being splashed into than out of the test area for these low rates of surface straw for which the horizontal component of splash is greater than with higher rates of surface straw.

3. If the assumption of equal splash into and out of the test area is false for the low levels of surface straw, then re-design the experimental apparatus using a wider pan border area and a rainfall simulator that provides uniform rainfall intensities for the test and border areas. Repeat the measurement of runoff and soil loss for the affected rates or at least the zero rate of surface straw.

4. Expand the scope of the study of the effects of residues on runoff and erosion to include other types of residues and other soils.

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APPENDIX A

RUNOFF AND SOIL LOSS DATA COLLECTED DURING RUNS FOR DIFFERENT COMBINATIONS OF SURFACE AND INCORPORATED STRAW

DATA FOR
SURFACE STRAW = 1 t/ha and INCORPORATED STRAW = 1 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	2.08	0.00	0.00	0.00
16	19.68	.30	227.84	1.38	13.89	.02
20	206.33	1.91	462.16	2.78	226.42	1.12
24	438.23	4.51	586.32	4.15	386.76	2.10
28	442.55	2.07	617.49	3.04	438.75	2.30
32	499.52	2.15	645.52	3.56	491.53	2.25
36	531.02	2.87	682.83	3.89	523.85	2.52
40	556.88	2.65	670.32	3.53	540.72	2.30
44	584.25	2.70	711.14	3.69	605.64	4.74
48	602.76	3.01	727.28	3.81	642.49	2.53
52	602.03	2.91	711.00	3.48	590.98	2.59
56	642.29	3.56	746.11	3.99	650.23	3.09
60	665.22	3.57	753.84	3.76	650.51	3.27
Pipeline Soil		15.08		12.86		12.16
WET RUNS						
4	281.72	1.48	243.59	1.10	285.43	1.65
8	616.44	2.92	611.16	2.57	699.94	3.72
12	652.49	3.05	684.05	2.90	707.41	3.95
16	746.78	3.51	730.98	3.28	748.12	4.10
20	751.47	3.83	740.19	3.60	741.64	4.47
24	740.92	3.84	765.12	4.01	754.08	4.57
28	746.99	3.89	696.53	3.26	755.69	5.10
30	401.46	2.32	377.68	1.93	426.79	2.98
Pipeline Soil		09.73		08.13		13.33
VERY WET RUNS						
4	553.46	2.45	607.05	2.48	698.34	3.28
8	770.96	3.37	748.33	3.23	754.16	4.65
12	764.51	3.51	793.51	3.66	734.16	4.33
16	808.57	3.93	783.66	3.70	745.88	4.52
20	777.18	3.72	787.07	3.70	745.65	4.69
24	762.29	3.56	778.09	3.59	743.66	4.63
28	769.28	3.75	777.51	3.82	740.20	4.93
30	386.29	1.99	406.38	2.16	391.98	2.46
Pipeline Soil		09.12		08.82		13.24

DATA FOR
SURFACE STRAW = 1 t/ha and INCORPORATED STRAW = 3 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	3.27	0.00	0.00	0.00
16	59.38	.20	60.56	.17	13.89	.02
20	304.38	1.64	291.48	1.54	226.42	1.12
24	429.14	2.07	407.07	1.86	386.76	2.10
28	510.90	2.76	477.66	2.16	438.75	2.30
32	518.41	2.47	582.08	4.23	491.53	2.25
36	563.40	3.14	557.71	2.25	523.85	2.52
40	580.56	2.78	578.89	2.35	540.72	2.30
44	593.40	2.92	599.68	2.62	605.64	4.74
48	614.34	3.02	610.19	3.04	642.49	2.53
52	626.84	3.06	634.54	3.01	590.98	2.59
56	634.92	2.81	648.59	3.22	650.23	3.09
60	681.85	3.23	669.52	3.21	650.51	3.27
Pipeline Soil		10.75		16.76		12.74
WET RUNS						
4	385.31	2.32	246.38	1.08	285.43	1.65
8	706.27	3.25	561.82	2.76	699.94	3.72
12	701.67	2.86	715.99	3.36	707.41	3.95
16	728.23	2.82	739.51	3.79	748.12	4.10
20	737.11	3.36	754.08	3.72	741.64	4.47
24	781.04	3.65	763.26	3.95	754.08	4.57
28	719.45	3.50	766.70	4.09	755.69	5.10
30	366.25	1.86	386.97	2.33	426.79	2.98
Pipeline Soil		08.06		09.21		10.43
VERY WET RUNS						
4	558.70	2.26	483.87	2.52	698.34	3.28
8	764.12	2.93	754.77	3.79	754.16	4.65
12	775.74	3.11	760.49	3.74	734.16	4.33
16	773.74	3.28	769.59	3.74	745.88	4.52
20	768.28	3.27	773.60	3.96	745.65	4.69
24	776.14	3.49	772.25	3.93	743.66	4.63
28	773.86	3.50	774.88	4.25	740.20	4.93
30	383.03	1.75	393.66	2.24	391.98	2.46
Pipeline Soil		06.12		06.14		07.27

DATA FOR
SURFACE STRAW = 1 t/ha and INCORPORATED STRAW = 5 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	5.98	.05	1.94	.02
16	33.60	.07	43.25	.14	41.02	.12
20	259.18	1.14	306.09	1.20	257.19	1.16
24	414.95	2.57	439.56	2.18	388.42	1.66
28	485.23	2.31	516.88	2.10	479.67	3.00
32	511.22	2.33	543.03	2.23	511.91	2.59
36	544.48	2.29	577.47	2.48	545.34	2.97
40	572.17	2.37	574.77	2.50	593.79	3.25
44	576.72	2.25	614.49	2.75	567.29	3.49
48	607.53	2.85	632.30	2.96	611.89	3.62
52	622.73	2.90	655.71	3.02	627.14	3.75
56	660.70	3.10	676.25	3.05	657.87	3.77
60	643.56	2.61	699.33	3.14	664.94	3.99
Pipeline Soil		11.04		17.25		17.91
WET RUNS						
4	165.96	.64	335.08	1.57	390.83	2.25
8	695.20	3.05	696.00	3.07	711.74	3.47
12	781.77	3.36	731.52	3.40	724.14	3.87
16	652.33	2.90	729.64	3.56	727.20	4.26
20	722.09	3.50	736.39	3.53	749.90	4.49
24	746.77	4.02	739.04	3.79	738.61	4.55
28	742.38	4.19	752.92	4.02	748.91	4.79
30	378.32	2.10	382.06	2.12	373.70	2.47
Pipeline Soil		08.31		08.31		11.57
VERY WET RUNS						
4	535.35	2.38	552.10	2.39	554.21	2.97
8	766.49	3.47	725.60	3.29	799.46	4.43
12	746.24	3.44	748.80	3.62	778.39	4.59
16	780.77	3.60	760.15	3.88	774.52	4.51
20	737.98	3.30	754.99	3.67	766.25	4.75
24	774.81	3.45	749.96	3.84	771.17	4.60
28	779.69	3.57	748.57	3.77	779.07	5.17
30	387.54	1.76	386.30	2.00	397.37	2.71
Pipeline Soil		07.80		03.29		11.43

DATA FOR
SURFACE STRAW = 1 t/ha and INCORPORATED STRAW = 7 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	49.93	0.00	0.00	0.00	0.00	0.00
12	64.00	.03	5.22	0.00	0.00	0.00
16	77.19	.17	98.92	3.13	31.83	.15
20	332.24	1.21	339.12	2.59	241.69	1.15
24	530.57	2.52	413.79	2.95	456.17	3.31
28	542.35	2.57	544.36	5.10	530.59	2.61
32	542.35	2.57	557.77	3.12	463.86	2.46
36	635.74	3.39	586.31	3.71	551.51	3.30
40	579.08	2.74	599.35	3.53	568.42	3.49
44	599.32	2.91	630.07	3.59	581.50	3.95
48	636.91	4.48	633.57	3.39	633.27	3.60
52	626.78	3.38	666.85	3.60	644.01	3.76
56	566.17	4.03	667.05	4.25	661.26	4.32
60	753.12	3.57	693.70	4.25	695.92	4.38
Pipeline Soil		19.97		14.36		15.14
WET RUNS						
4	284.20	1.07	270.41	1.42	374.94	2.52
8	623.76	2.74	683.24	3.81	753.86	4.23
12	724.73	3.28	759.41	4.32	762.41	4.62
16	737.39	3.49	751.09	4.36	774.35	4.82
20	742.06	3.34	774.90	4.59	778.50	5.53
24	796.99	3.41	760.01	4.52	774.45	5.31
28	754.18	3.61	770.41	4.89	782.47	5.30
30	388.90	3.12	396.30	2.80	401.87	2.93
Pipeline Soil		09.29		11.52		16.16
VERY WET RUNS						
4	602.44	2.61	549.68	2.91	535.66	2.71
8	738.88	3.45	781.83	4.19	786.76	4.17
12	765.71	3.43	781.35	4.36	794.04	4.32
16	776.94	3.75	783.66	4.35	795.54	4.30
20	779.41	3.95	785.96	4.34	796.61	4.62
24	770.51	3.81	790.40	4.66	804.07	4.48
28	756.81	4.02	784.43	4.90	795.43	4.67
30	462.72	2.67	399.71	2.59	411.43	2.54
Pipeline Soil		09.78		10.96		10.16

DATA FOR
SURFACE STRAW = 3 t/ha and INCORPORATED STRAW = 1 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	4.21	0.00	0.00	0.00
16	4.21	0.00	8.92	0.00	1.55	0.00
20	13.71	0.00	19.89	.02	6.02	0.00
24	78.59	.68	100.55	.32	109.07	.06
28	260.02	2.10	325.01	1.12	302.59	.58
32	351.51	1.40	435.49	1.19	411.69	.71
36	555.36	2.99	521.41	1.61	510.56	1.60
40	544.94	1.70	579.98	1.25	543.85	1.20
44	621.29	1.77	576.56	1.32	597.20	1.42
48	657.18	2.26	731.05	1.57	662.05	1.97
52	673.95	2.07	746.20	1.67	708.83	1.52
56	694.86	2.14	742.24	2.03	733.76	1.67
60	714.77	2.02	743.72	2.18	744.94	1.76
Pipeline Soil		10.65		11.04		08.66
WET RUNS						
4	321.49	1.43	308.17	1.11	583.25	1.70
8	732.87	2.02	784.45	2.67	791.99	2.22
12	746.83	2.20	801.46	2.48	774.55	1.94
16	765.50	1.97	801.82	2.34	794.60	1.85
20	752.58	1.72	807.04	2.20	860.77	2.25
24	746.28	1.66	847.47	1.97	734.54	1.85
28	765.79	1.65	866.85	2.36	790.25	1.92
30	373.22	.89	444.32	1.19	404.39	1.13
Pipeline Soil		05.96		06.02		07.39
VERY WET RUNS						
4	392.91	1.16	396.30	1.00	421.12	1.15
8	784.40	1.69	859.67	1.83	831.77	1.84
12	741.64	1.42	826.70	1.68	784.62	2.62
16	780.64	1.35	811.99	1.57	819.40	1.65
20	781.45	1.38	830.94	1.69	811.25	1.66
24	762.48	1.29	820.37	1.73	812.78	1.69
28	777.82	1.36	848.12	1.84	825.60	1.67
30	386.13	.78	462.11	.95	417.35	.85
Pipeline Soil		03.68		05.09		03.99

DATA FOR
SURFACE STRAW = 3 t/ha and INCORPORATED STRAW = 3 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	10.53	0.00	2.94	.14
16	12.08	.01	9.82	.01	4.87	0.00
20	17.49	0.00	27.45	.06	37.01	.02
24	52.34	.03	193.23	.92	214.37	.38
28	243.41	.25	331.70	1.46	319.67	.72
32	357.03	1.45	554.46	3.09	415.31	1.41
36	432.17	1.22	426.98	1.39	465.10	1.09
40	517.35	1.32	554.15	1.61	530.08	1.25
44	658.68	3.44	617.28	1.84	601.59	1.28
48	655.37	1.67	638.52	1.82	643.88	1.48
52	687.33	1.54	672.78	1.84	683.49	1.65
56	712.99	1.79	668.85	2.02	693.28	1.53
60	715.84	2.17	712.35	2.27	724.60	1.59
Pipeline Soil		11.19		09.25		09.92
WET RUNS						
4	359.80	1.59	322.38	.96	293.67	1.01
8	762.47	2.62	733.14	1.85	763.03	2.10
12	791.99	2.37	739.21	1.81	763.19	1.81
16	788.44	2.20	759.29	1.83	758.14	1.68
20	786.92	2.23	760.87	1.83	775.58	1.73
24	796.70	2.22	760.59	1.66	764.27	1.56
28	815.94	2.12	759.98	1.62	772.76	1.55
30	406.98	1.16	386.99	.94	394.61	.91
Pipeline Soil		04.94		02.98		05.58
VERY WET RUNS						
4	449.30	1.24	426.56	1.37	381.79	.90
8	813.77	1.89	755.67	1.70	765.14	1.53
12	811.71	2.15	747.26	1.70	774.73	1.45
16	839.71	1.91	766.16	1.67	786.44	1.34
20	787.50	1.72	780.10	1.65	779.03	1.32
24	822.76	1.73	787.94	1.60	780.03	1.36
28	820.00	1.92	780.25	1.64	789.46	1.30
30	416.27	1.06	393.15	.89	399.06	.74
Pipeline Soil		04.23		03.09		04.42

DATA FOR
SURFACE STRAW = 3 t/ha and INCORPORATED STRAW = 5 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	1.88	.04	2.61	.03
16	0.00	0.00	2.66	0.00	4.47	.02
20	15.67	.03	3.49	0.00	9.58	.02
24	176.17	.48	239.43	.69	128.75	.71
28	345.08	.93	452.30	1.21	296.00	1.26
32	414.51	.78	500.07	1.25	427.32	2.19
36	529.23	.95	534.71	1.45	459.82	1.17
40	626.70	1.22	569.02	1.65	524.12	1.46
44	597.39	1.00	656.18	1.81	604.18	1.68
48	717.53	1.30	719.09	2.26	642.25	1.58
52	757.50	1.20	662.69	1.59	679.53	1.58
56	717.71	1.24	703.57	1.89	698.65	1.67
60	717.10	1.61	753.03	1.87	720.96	1.70
Pipeline Soil		06.17		10.10		13.38
WET RUNS						
4	365.80	1.89	273.82	.94	320.51	1.14
8	780.22	3.03	760.42	2.05	783.71	1.99
12	803.93	2.03	760.37	1.77	794.60	1.80
16	796.87	2.01	790.00	1.79	806.88	1.86
20	821.20	1.85	794.65	1.84	807.47	1.81
24	814.03	1.91	790.11	1.68	798.63	1.77
28	815.94	2.06	790.45	1.72	810.31	1.83
30	405.76	1.24	406.54	.97	414.75	.99
Pipeline Soil		06.52		03.78		07.64
VERY WET RUNS						
4	443.49	1.05	386.71	.89	400.33	.98
8	852.42	1.67	799.72	1.57	799.01	1.56
12	777.21	1.40	792.25	1.39	784.75	1.46
16	817.41	1.43	794.47	1.37	799.47	1.54
20	804.12	1.53	787.67	1.40	799.21	1.44
24	830.76	1.43	805.19	1.33	794.74	1.46
28	817.81	1.11	777.19	1.61	808.65	1.46
30	423.94	.78	395.25	.73	407.89	.77
Pipeline Soil		04.77		04.87		06.59

DATA FOR
SURFACE STRAW = 3 t/ha and INCORPORATED STRAW = 7 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	7.18	.02
16	51.76	.01	6.93	0.00	4.16	.03
20	46.28	.02	83.38	0.00	27.00	.10
24	290.09	1.02	337.07	.51	211.99	.56
28	417.00	1.53	406.71	.67	365.58	.79
32	482.63	1.38	509.31	.96	495.06	2.39
36	582.33	1.68	555.98	1.06	522.90	1.26
40	581.21	1.52	580.36	1.04	560.31	1.24
44	631.94	1.96	623.04	1.17	627.19	1.50
48	675.93	2.01	662.86	1.47	656.52	1.63
52	643.75	1.98	719.57	1.69	717.28	1.87
56	713.58	2.27	691.72	1.69	709.62	2.22
60	746.28	2.29	729.03	1.56	724.91	1.73
Pipeline Soil		10.51		09.62		13.19
WET RUNS						
4	343.91	1.29	298.49	.85	374.46	1.55
8	754.95	2.14	769.23	1.72	775.19	2.57
12	774.71	1.85	799.49	1.85	809.14	2.61
16	789.39	1.85	807.22	1.72	799.66	2.54
20	797.87	1.97	804.69	1.80	823.36	2.45
24	808.04	2.02	808.44	1.69	834.47	2.49
28	787.73	2.04	846.73	1.68	785.63	2.33
30	403.76	.97	416.46	.87	417.61	1.29
Pipeline Soil		04.47		03.22		09.72
VERY WET RUNS						
4	411.69	1.26	393.52	.96	413.52	1.02
8	778.69	1.74	859.09	1.76	819.38	1.67
12	815.83	1.75	824.63	1.64	817.38	1.71
16	850.55	1.71	839.68	1.67	825.70	1.70
20	812.39	1.74	841.66	1.69	824.11	1.75
24	866.12	1.59	827.48	1.71	841.52	1.78
28	812.50	1.67	827.24	1.64	771.34	1.79
30	418.32	.94	419.13	.89	411.15	1.05
Pipeline Soil		05.84		04.84		05.64

APPENDIX B

RUNOFF AND SOIL LOSS DATA COLLECTED DURING RUNS FOR PLOTS WITH DIFFERENT RATES OF SURFACE STRAW

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH SURFACE STRAW OF 0 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	2.41	.04	2.50	.01	0.00	0.00
16	110.50	1.76	153.48	1.11	65.95	.25
20	264.81	2.22	306.00	1.67	265.68	1.90
24	321.70	2.49	368.08	1.95	345.47	2.14
28	370.98	2.38	412.63	2.35	383.00	2.33
32	394.84	2.71	441.54	2.78	414.23	2.47
36	420.69	2.55	460.73	2.48	431.38	2.62
40	430.73	2.72	475.50	2.59	443.84	2.74
44	471.31	4.08	509.46	2.85	476.29	3.05
48	468.68	2.92	490.64	2.75	475.57	3.09
52	485.86	3.08	535.24	2.96	509.49	3.12
56	489.73	3.03	510.77	2.90	512.23	3.23
60	514.22	3.36	560.80	3.05	632.86	4.07
P		19.57		20.61		25.89
WET RUNS						
4	213.65	1.10	344.68	1.70	290.65	2.00
8	331.63	1.48	546.77	2.85	608.53	5.40
12	383.12	2.03	621.71	3.40	614.42	3.55
16	523.39	3.41	656.89	3.95	615.59	3.87
20	598.12	4.62	699.15	4.32	724.55	5.00
24	651.09	5.28	620.31	4.18	513.90	3.64
28	655.25	5.50	689.43	4.92	629.72	4.58
30	329.41	2.95	335.29	2.67	319.81	2.74
P		9.19		15.28		14.76
VERY WET RUNS						
4	416.39	3.17	530.30	3.16	506.77	3.22
8	699.34	5.01	743.49	4.71	607.78	4.39
12	683.63	5.28	653.93	4.37	685.34	4.71
16	663.61	5.35	691.61	4.81	639.53	4.75
20	680.79	5.73	712.23	5.02	653.06	5.33
24	683.50	5.70	692.03	5.03	613.96	6.33
28	689.10	5.97	720.66	5.36	730.55	5.75
30	343.10	2.98	347.89	2.85	298.99	3.00
P		11.68		11.05		15.80

P = Soil from pipeline cleanout

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH SURFACE STRAW OF 0.5 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	3.49	.04	0.00	0.00
16	36.34	.18	20.85	.05	30.98	.05
20	218.74	1.01	168.97	1.18	251.17	.92
24	345.68	2.31	312.68	1.50	407.16	2.34
28	377.19	2.21	380.91	1.80	454.14	2.05
32	466.09	2.30	426.36	2.36	500.32	2.51
36	383.34	2.22	457.64	3.02	510.99	2.67
40	456.36	3.51	495.16	3.48	519.27	3.11
44	482.20	3.29	512.45	3.57	554.11	2.87
48	494.85	2.87	542.49	3.53	597.74	2.84
52	499.31	3.16	565.74	4.02	607.82	3.26
56	527.89	3.26	602.29	4.38	581.20	3.06
60	550.56	3.59	623.39	4.85	686.41	3.66
P		19.21		20.29		22.38
WET RUNS						
4	200.29	1.44	285.07	1.37	298.51	1.42
8	573.91	3.46	693.31	4.12	650.51	2.87
12	654.93	3.88	722.87	5.14	673.17	2.87
16	675.53	4.63	757.84	4.95	687.20	3.16
20	711.33	5.47	744.83	5.76	690.29	3.38
24	724.12	6.35	718.85	5.77	716.97	3.68
28	747.24	7.09	737.15	6.23	695.66	3.86
30	379.40	3.65	388.07	3.36	344.16	1.99
P		12.17		15.40		6.84
VERY WET RUNS						
4	588.10	4.86	671.96	4.37	539.02	2.72
8	749.69	6.06	678.07	4.44	739.90	3.81
12	754.19	6.30	703.74	5.90	694.05	3.62
16	745.67	6.66	748.04	4.13	730.42	3.82
20	746.26	7.32	746.88	6.23	719.74	3.93
24	750.25	7.35	732.08	6.03	733.86	4.32
28	732.17	7.52	718.34	5.52	729.24	4.59
30	397.33	4.19	320.44	2.97	355.77	2.43
P		20.29		14.71		14.66

P = Soil from pipeline cleanout

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH SURFACE STRAW OF 1 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	7.61	.06	0.00	0.00	0.00	0.00
8	3.89	.06	2.65	.02	0.00	0.00
12	5.61	.06	5.05	0.00	0.00	0.00
16	7.55	.03	5.67	.01	0.00	0.00
20	198.70	.94	71.48	.18	27.10	.10
24	389.67	1.52	308.33	1.49	255.37	1.21
28	452.91	1.68	387.05	1.31	329.99	1.43
32	501.65	1.72	442.27	1.42	407.89	1.61
36	568.19	2.08	476.09	1.57	438.92	1.73
40	574.62	2.27	518.25	1.84	493.86	2.48
44	594.86	2.42	552.42	1.88	507.46	2.28
48	630.19	2.88	581.60	2.13	548.56	2.50
52	689.98	3.42	632.67	2.46	578.44	3.03
56	708.00	3.18	670.39	2.98	623.77	3.18
60	735.12	3.42	683.34	3.12	644.11	3.84
P		14.46		18.33		19.50
WET RUNS						
4	388.36	2.35	378.02	1.49	304.96	2.35
8	751.06	4.22	758.74	4.14	697.08	4.29
12	734.53	4.35	757.76	3.92	724.06	4.21
16	743.20	4.66	769.68	4.23	739.00	4.57
20	748.39	4.70	758.59	4.19	734.07	4.74
24	735.59	4.66	776.25	4.57	737.41	4.76
28	737.15	4.40	763.47	4.72	739.90	4.99
30	375.07	2.51	388.65	2.44	374.13	2.70
P		11.88		12.84		8.97
VERY WET RUNS						
4	537.23	2.62	580.00	3.04	535.71	3.24
8	750.38	4.08	652.78	5.54	683.28	4.12
12	786.46	4.09	662.25	3.17	716.13	4.42
16	787.56	4.29	745.15	4.30	718.45	4.52
20	808.49	4.37	776.79	4.64	724.88	4.68
24	767.28	4.47	827.09	4.83	731.31	4.80
28	780.30	4.38	707.22	4.31	744.17	4.91
30	392.94	2.30	392.81	2.49	374.07	2.41
P		10.21		11.81		9.94

P = Soil from pipeline cleanout

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH SURFACE STRAW OF 2 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	2.79	0.00	.98	0.00	0.00	0.00
16	4.65	0.00	2.53	.01	4.79	.01
20	22.10	.01	8.69	.01	29.54	.05
24	148.60	.60	110.21	.31	234.78	.92
28	301.79	1.27	326.44	1.59	351.71	1.20
32	371.25	1.53	374.43	1.31	413.39	1.17
36	456.92	1.51	438.11	1.60	504.16	2.19
40	490.28	1.83	456.95	2.15	548.98	2.19
44	587.39	2.39	542.10	2.39	590.90	2.20
48	665.93	3.12	608.14	3.11	638.94	2.43
52	729.68	4.47	630.13	3.51	709.85	3.08
56	755.44	4.27	698.00	3.67	716.81	3.37
60	765.98	4.33	721.53	4.30	749.70	3.01
P		10.15		12.94		15.96
WET RUNS						
4	410.19	2.22	438.51	2.93	382.93	1.94
8	793.70	3.38	788.45	4.28	773.34	3.45
12	808.62	4.61	808.64	4.46	820.04	3.39
16	819.80	5.59	812.19	4.51	813.70	3.51
20	813.01	5.57	791.90	4.76	821.65	3.53
24	822.80	5.49	795.87	4.81	832.71	3.74
28	827.50	5.58	789.97	4.91	806.77	3.94
30	413.89	2.81	402.55	2.73	404.86	2.72
P		11.95		6.95		9.49
VERY WET RUNS						
4	502.24	2.39	528.40	2.65	486.01	1.72
8	836.63	3.99	798.44	3.63	794.32	2.72
12	833.53	3.88	792.50	3.70	812.68	2.74
16	823.62	3.88	798.10	3.73	805.66	2.60
20	807.17	3.96	806.84	4.16	803.69	2.77
24	807.49	3.86	797.89	4.66	798.63	2.78
28	789.15	3.76	840.40	4.34	805.23	2.84
30	404.53	2.02	396.88	2.02	406.07	1.48
P		11.66		9.60		5.22

P = Soil from pipeline cleanout

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH SURFACE STRAW OF 4 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	1.44	0.00	0.00	0.00
12	0.00	0.00	4.94	.02	0.00	0.00
16	3.19	.05	5.16	.02	0.00	0.00
20	9.97	.07	6.22	.02	46.67	.06
24	25.90	.08	6.68	.02	10.68	.02
28	153.51	.49	8.91	.01	60.97	.04
32	281.16	.60	92.34	.16	194.18	.21
36	386.04	.93	280.69	.68	331.59	.37
40	602.49	1.60	464.93	.99	469.01	.53
44	691.69	1.62	652.27	1.80	733.42	.65
48	746.46	1.51	697.22	1.20	749.08	.66
52	753.72	1.57	717.73	1.19	783.05	.76
56	768.38	1.50	713.30	1.17	648.96	.58
60	776.26	1.50	718.35	1.16	636.78	.58
P		10.32		7.31		2.38
WET RUNS						
4	277.13	1.08	276.14	.84	211.06	.56
8	761.10	2.15	753.81	1.85	721.55	1.24
12	765.69	2.04	779.11	1.52	752.31	1.06
16	777.12	1.92	772.15	1.48	750.35	.96
20	782.05	1.92	763.31	1.39	764.79	.88
24	786.67	1.87	818.25	1.40	766.97	.81
28	798.30	1.87	770.85	1.37	803.61	.80
30	394.23	.98	391.98	.82	399.75	.47
P		2.38		5.59		4.32
VERY WET RUNS						
4	372.84	.74	359.55	.71	302.29	.34
8	789.42	1.54	771.81	1.60	744.84	.81
12	790.51	1.45	804.34	1.35	707.00	.78
16	793.86	1.43	789.50	1.33	846.89	.77
20	783.74	1.31	792.06	1.30	777.62	.73
24	796.19	1.33	798.99	1.48	780.99	.66
28	799.50	1.35	793.75	1.25	793.81	.66
30	400.87	.78	407.32	.72	383.17	.38
P		5.60		4.77		2.70

P = Soil from pipeline cleanout

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH SURFACE STRAW OF 6 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	2.67	.03	0.00	0.00
16	1.56	0.00	4.56	.02	0.00	0.00
20	18.97	0.00	6.23	.02	4.50	.02
24	18.37	0.00	6.25	0.00	15.06	.04
28	95.10	.07	5.99	.06	9.04	.03
32	191.69	.21	20.83	.02	52.33	.02
36	273.02	.32	98.00	.24	191.99	.11
40	420.27	.52	431.47	.96	414.81	.38
44	568.83	.59	643.37	1.00	575.50	.49
48	636.57	.68	636.29	.74	638.66	.44
52	684.50	.68	668.01	.80	675.94	.36
56	703.95	.69	674.04	.72	676.08	.38
60	733.41	.81	699.92	.76	698.09	.34
P		6.14		7.33		3.24
WET RUNS						
4	379.57	.76	198.05	.45	167.45	.32
8	568.80	1.00	740.20	.96	695.99	.91
12	752.37	1.01	782.14	1.08	744.26	.73
16	774.46	1.00	792.29	.85	737.29	.67
20	777.48	.89	801.23	.64	797.18	.66
24	779.19	.88	758.18	.59	804.41	.68
28	781.03	.93	779.54	.55	802.98	.59
30	393.60	.50	375.96	.50	384.78	.36
P		7.30		3.03		2.97
VERY WET RUNS						
4	260.18	.44	262.99	.34	213.69	.20
8	767.35	1.11	788.07	.81	746.29	.51
12	788.08	1.02	754.87	.74	767.83	.47
16	783.06	.99	764.10	.68	761.62	.40
20	780.99	.90	779.06	.59	751.14	.37
24	791.36	.95	765.25	.58	779.81	.38
28	793.61	.94	779.46	.58	757.01	.40
30	398.99	.49	386.60	.31	405.82	.28
P		6.57		4.42		1.92

P = Soil from pipeline cleanout

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH SURFACE STRAW OF 8 t/ha

	REP # 1		REP # 2		REP # 3	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS						
4	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00
12	5.19	0.00	0.00	0.00	7.89	.03
16	7.07	0.00	3.16	.08	8.54	.05
20	6.72	.01	5.94	.02	8.46	.01
24	15.32	.01	6.56	.05	11.88	.03
28	14.47	.02	20.24	.02	23.00	.03
32	41.66	.01	131.92	.12	63.02	.04
36	139.01	.03	242.84	.24	155.58	.13
40	311.72	.20	355.38	.36	332.10	.33
44	569.20	.41	466.70	.28	543.72	.39
48	679.09	.52	525.71	.35	700.52	.40
52	687.76	.40	551.40	.22	647.66	.36
56	699.21	.49	556.56	.32	724.27	.37
60	690.88	.30	562.90	.29	649.56	.32
P		.34		1.46		2.31
WET RUNS						
4	159.62	.24	108.36	.37	139.65	.33
8	710.52	.67	626.96	1.38	764.85	.83
12	773.02	.66	667.69	.91	750.48	.57
16	776.28	.40	678.10	.66	763.07	.53
20	784.67	.34	696.19	.69	769.81	.53
24	842.15	.34	710.15	.61	767.82	.43
28	716.35	.29	693.52	.51	761.14	.37
30	385.27	.14	364.30	.32	380.74	.26
P		1.66		3.78		3.01
VERY WET RUNS						
4	196.34	.10	142.41	.23	196.51	.14
8	741.95	.37	663.95	.62	711.78	.46
12	747.93	.31	686.68	.52	742.68	.34
16	761.12	.26	744.39	.42	904.43	.27
20	761.53	.20	704.67	.39	776.06	.30
24	751.53	.23	723.40	.42	831.75	.30
28	708.21	.19	736.87	.38	760.95	.17
30	381.36	.11	359.45	.21	386.37	.13
P		1.93		2.76		2.41

P = Soil from pipeline cleanout

APPENDIX C

RUNOFF AND SOIL LOSS DATA COLLECTED DURING RUNS FOR PLOTS WITH DIFFERENT RATES OF INCORPORATED STRAW

DATA FOR
RUNOFF FROM PLOTS WITH INCORPORATED STRAW OF 0 t/ha

	RUNOFF				
TIME (MIN)	REP # 1 (g)	REP # 2 (g)	REP # 3 (g)	REP # 4 (g)	REP # 5 (g)
DRY RUNS					
4	.00	.00	.01	.01	.01
8	.00	.00	.01	.01	3.98
12	14.86	13.60	31.60	7.87	7.81
16	275.61	275.56	238.13	173.71	140.07
20	374.32	380.40	365.56	317.92	262.78
24	428.20	425.25	399.08	383.57	334.60
28	462.48	448.87	433.66	423.77	383.69
32	478.39	473.98	434.66	451.88	417.66
36	501.95	508.82	485.50	470.47	443.46
40	508.67	506.12	503.17	490.90	451.01
44	514.96	526.45	508.40	503.09	474.72
48	525.85	536.46	530.64	519.50	497.95
52	541.33	556.55	539.71	531.79	497.04
56	548.01	554.15	534.44	542.76	529.97
60	558.65	591.84	572.99	559.42	559.17
WET RUNS					
4	316.10	179.85	206.96	220.41	210.43
8	503.82	351.79	331.00	456.02	319.05
12	518.89	421.11	486.45	579.19	582.04
16	556.85	617.62	617.33	641.02	641.59
20	500.78	632.44	655.85	664.68	653.30
24	576.24	728.93	674.14	681.90	704.58
28	649.72	733.50	692.97	727.16	730.74
30	328.57	377.13	350.44	363.20	365.90
VERY WET RUNS					
4	584.13	397.69	576.73	614.55	610.43
8	719.99	766.76	693.43	727.94	726.47
12	722.61	774.57	723.84	751.20	732.48
16	723.90	752.00	741.21	745.52	735.57
20	716.58	759.57	751.40	756.96	740.10
24	732.10	778.15	746.74	742.71	731.63
28	731.27	767.34	749.39	748.99	729.37
30	364.64	386.48	371.63	378.82	369.92

DATA FOR
SOIL LOSS FROM PLOTS WITH INCORPORATED STRAW OF 0 t/ha

	SOIL LOSS				
TIME (MIN)	REP # 1 (g)	REP # 2 (g)	REP # 3 (g)	REP # 4 (g)	REP # 5 (g)
DRY RUNS					
4	.00	.00	.01	.01	.01
8	.00	.00	.01	.01	.01
12	.24	.03	.11	.01	.02
16	4.75	3.62	1.68	1.08	.70
20	3.15	2.92	2.93	2.08	1.55
24	3.41	3.17	2.28	2.75	2.21
28	4.92	3.22	2.88	3.21	2.49
32	3.57	3.36	2.76	3.18	2.58
36	4.22	3.78	3.15	3.21	2.60
40	4.21	3.77	3.33	3.69	3.04
44	4.16	3.84	3.22	3.60	2.88
48	4.09	3.72	3.38	3.58	3.31
52	4.12	3.38	3.62	3.43	3.33
56	4.12	3.49	3.54	3.49	3.76
60	3.95	3.71	4.00	3.45	3.81
P	16.25	20.07	13.10	17.76	22.09
WET RUNS					
4	2.18	.65	1.19	1.60	1.00
8	2.91	1.38	1.67	2.93	1.56
12	3.13	2.22	3.87	4.18	4.67
16	3.70	4.28	5.56	5.47	5.39
20	3.81	4.84	6.73	6.32	5.89
24	5.00	6.86	7.31	7.10	7.01
28	6.17	7.04	7.67	7.98	7.66
30	3.44	3.69	3.95	4.48	4.23
P	8.51	14.13	16.99	18.46	12.38
VERY WET RUNS					
4	5.10	3.10	3.94	4.67	5.79
8	6.75	5.79	5.33	6.12	6.80
12	7.21	6.37	6.74	6.91	6.84
16	7.31	6.70	7.00	7.17	6.82
20	7.29	7.45	7.42	7.54	7.01
24	7.81	7.77	7.58	7.86	6.72
28	7.75	7.54	7.84	8.08	6.82
30	3.87	3.95	3.71	4.01	3.69
P	9.21	16.20	10.69	20.05	19.21

P = Soil from pipeline cleanout

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH INCORPORATED STRAW OF 2.2 t/ha

	REP # 1		REP # 2	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS				
4	.56	.01	.01	.01
8	3.79	.01	4.40	.01
12	33.69	.21	23.70	.02
16	414.24	7.10	275.85	1.70
20	448.84	4.86	419.93	2.84
24	512.27	9.15	455.97	2.50
28	510.97	6.93	487.06	2.70
32	514.67	5.49	522.36	3.23
36	549.97	5.08	544.05	3.55
40	552.91	5.00	543.71	3.43
44	560.29	5.10	556.58	3.65
48	568.71	5.39	576.11	3.92
52	580.61	5.15	583.36	3.81
56	591.91	4.75	587.38	3.59
60	602.54	4.78	599.04	4.00
P		17.26		25.65
WET RUNS				
4	289.99	1.60	276.25	1.40
8	464.32	2.48	551.19	2.98
12	454.66	2.58	666.50	4.49
16	428.91	2.59	651.33	3.62
20	514.19	4.08	707.67	5.12
24	591.71	5.35	699.90	5.71
28	596.01	5.69	720.36	6.28
30	306.25	2.98	358.41	3.35
P		14.04		16.22
VERY WET RUNS				
4	506.20	4.55	607.79	3.92
8	736.46	7.45	734.38	5.40
12	736.54	7.95	733.39	5.81
16	742.07	8.18	741.28	6.16
20	749.14	8.86	752.89	6.92
24	749.64	8.67	743.93	6.93
28	719.67	8.47	768.23	7.02
30	366.83	4.49	360.05	3.27
P		9.89		13.03

P = Soil from pipeline cleanout

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH INCORPORATED STRAW OF 4.5 t/ha

	REP # 1		REP # 2	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS				
4	.01	.01	.01	.01
8	.01	.01	5.06	.01
12	34.54	.56	15.11	.01
16	269.80	3.21	193.20	1.20
20	400.71	3.77	366.98	2.97
24	439.43	3.07	407.86	2.63
28	485.67	3.96	444.46	3.01
32	501.72	4.02	466.77	3.32
36	519.82	4.43	489.93	3.34
40	526.73	4.34	499.15	3.34
44	532.83	4.38	519.51	3.69
48	568.39	4.65	532.45	3.34
52	555.44	4.29	546.90	3.64
56	576.37	4.21	558.03	3.40
60	576.77	4.31	572.85	3.30
P		21.97		21.15
WET RUNS				
4	286.86	1.49	97.35	.18
8	565.09	2.55	350.47	1.65
12	626.89	3.31	513.81	3.04
16	652.05	3.88	692.67	4.68
20	681.87	4.55	702.83	5.11
24	699.54	5.14	706.62	5.65
28	707.92	5.69	742.41	6.21
30	356.98	2.97	384.51	3.55
P		12.11		11.17
VERY WET RUNS				
4	587.13	3.32	606.70	4.97
8	727.42	4.99	751.31	6.42
12	722.80	5.96	792.06	7.44
16	744.24	6.41	768.69	7.43
20	746.84	6.95	736.92	8.13
24	757.89	7.69	865.94	8.28
28	757.40	7.87	837.01	9.12
30	381.60	4.26	396.50	4.57
P		11.33		22.43

P = Soil from pipeline cleanout

RUNOFF AND SOIL LOSS DATA FOR
PLOTS WITH INCORPORATED STRAW OF 6.7 t/ha

	REP # 1		REP # 2	
TIME (MIN)	RUNOFF (g)	SOIL LOSS (g)	RUNOFF (g)	SOIL LOSS (g)
DRY RUNS				
4	.20	.03	.99	.03
8	5.74	.04	3.38	.04
12	157.79	1.76	78.58	.47
16	437.55	4.44	346.67	3.30
20	554.38	5.84	409.64	2.96
24	531.53	4.42	452.56	3.10
28	551.95	4.58	469.03	3.41
32	579.06	5.69	506.26	3.40
36	582.00	4.66	501.76	3.57
40	593.26	4.95	526.94	3.81
44	601.95	4.87	544.03	3.74
48	606.43	4.86	556.55	3.97
52	615.99	5.02	568.39	4.26
56	620.09	4.89	565.33	4.20
60	631.09	4.75	585.11	4.18
P		22.96		22.22
WET RUNS				
4	237.93	1.23	200.85	.82
8	604.94	3.08	374.86	2.19
12	618.26	3.48	472.59	2.84
16	600.69	3.89	541.46	3.67
20	657.68	4.95	630.51	5.17
24	668.64	5.15	648.33	5.71
28	674.70	5.42	703.47	6.58
30	344.30	2.92	347.51	3.40
P		11.71		15.83
VERY WET RUNS				
4	570.46	3.96	547.39	3.91
8	700.50	5.04	707.66	5.82
12	710.91	5.63	698.83	6.32
16	717.80	6.39	708.96	6.79
20	699.03	5.72	710.01	6.89
24	708.67	6.36	742.14	7.49
28	717.81	7.11	724.40	7.48
30	358.02	3.47	380.01	3.97
P		13.84		20.98

P = Soil from pipeline cleanout

DATA FOR
RUNOFF FROM PLOTS WITH INCORPORATED STRAW OF 9 t/ha

	RUNOFF				
TIME (MIN)	REP # 1 (g)	REP # 2 (g)	REP # 3 (g)	REP # 4 (g)	REP # 5 (g)
DRY RUNS					
4	.30	.46	.00	.00	.01
8	1.85	6.90	.00	.00	38.21
12	198.61	135.61	46.32	88.46	66.25
16	411.39	356.85	331.60	371.81	296.49
20	481.75	418.66	412.11	445.88	383.30
24	515.60	491.06	453.72	491.83	426.75
28	548.42	484.18	485.10	522.74	468.70
32	578.90	495.06	500.64	547.70	479.79
36	601.57	510.13	523.05	561.30	499.65
40	596.63	530.10	527.98	566.05	513.49
44	601.15	531.12	531.70	589.34	532.81
48	614.22	537.79	543.70	587.90	540.35
52	620.54	551.68	562.08	601.52	552.92
56	619.33	554.96	565.95	612.41	564.18
60	621.43	551.95	583.29	612.13	988.06
WET RUNS					
4	188.47	156.07	274.96	321.60	223.38
8	477.45	546.89	574.63	568.20	654.90
12	577.94	603.02	640.20	594.06	668.03
16	648.89	643.56	419.24	623.67	676.39
20	693.92	656.24	514.17	648.83	696.85
24	705.14	654.81	674.50	673.22	702.79
28	711.10	655.39	677.97	700.29	691.43
30	351.12	333.78	346.88	356.06	349.77
VERY WET RUNS					
4	587.36	533.91	570.12	578.88	568.36
8	715.11	665.50	702.96	718.07	714.23
12	735.19	672.68	705.42	723.27	717.59
16	716.02	673.89	702.34	732.02	752.12
20	731.48	679.13	724.25	737.92	700.33
24	735.82	673.11	702.58	743.96	758.27
28	719.68	688.93	725.03	739.23	695.95
30	383.48	340.79	360.96	370.46	380.05

DATA FOR
SOIL LOSS FROM PLOTS WITH INCORPORATED STRAW OF 9 t/ha

	SOIL LOSS				
TIME (MIN)	REP # 1 (g)	REP # 2 (g)	REP # 3 (g)	REP # 4 (g)	REP # 5 (g)
DRY RUNS					
4	.01	.00	.00	.00	.01
8	.04	.00	.00	.00	.04
12	7.85	1.02	.28	1.05	.34
16	6.09	3.08	3.24	2.31	1.87
20	6.54	3.47	3.29	2.89	2.49
24	5.71	5.36	3.14	3.87	2.97
28	5.54	3.86	3.35	4.44	3.39
32	5.61	4.18	3.57	4.81	3.47
36	5.17	4.29	4.36	4.78	3.54
40	5.59	5.28	3.38	4.80	3.63
44	5.12	4.52	3.56	4.94	3.74
48	5.20	4.48	3.97	4.50	3.57
52	4.84	4.58	4.20	4.47	4.32
56	4.94	4.79	4.60	4.64	3.99
60	5.34	4.50	4.35	4.47	3.94
P	10.51	21.93	24.59	23.15	24.89
WET RUNS					
4	.74	1.02	1.41	1.34	1.15
8	2.51	3.76	3.04	2.57	3.60
12	3.72	4.56	3.60	2.97	3.96
16	4.92	4.92	4.89	3.45	4.30
20	5.92	5.42	3.42	4.06	4.79
24	6.39	5.85	4.75	4.63	5.35
28	6.98	6.17	5.01	5.41	5.58
30	5.02	3.39	2.51	2.97	3.03
P	8.56	5.90	13.88	12.99	14.99
VERY WET RUNS					
4	4.16	4.07	3.27	3.56	3.74
8	5.59	5.81	4.32	4.98	5.28
12	6.44	6.24	4.80	5.37	5.70
16	6.28	6.16	4.93	5.71	6.54
20	7.16	6.53	5.57	6.22	6.47
24	6.86	6.84	5.55	6.67	7.33
28	7.19	7.33	6.11	6.72	7.11
30	4.21	3.69	3.13	3.46	3.77
P	10.42	20.03	15.18	12.54	23.94

P = Soil from pipeline cleanout

VITA

The author was born November 11, 1943 near Pontotoc, Mississippi. He was raised on a farm and received his elementary and secondary education in Springville and Algoma, Mississippi, graduating from Algoma High School in 1961. His parents, Lesley and Opal McGregor are retired and reside in Oxford, Mississippi. One sister, Kallie Sue, is deceased. His other sister, Brenda Kay Franklin, is an elementary school teacher in Morton, Mississippi. His brother, Kermit, is Director of Public Relations for The Baptist Children's Village in Jackson, Mississippi.

The author received the Bachelor of Science degree in Agricultural Engineering from Mississippi State University in 1967. Before graduation, he received experience as an engineering aide with both the Delta Branch Experiment Station, Stoneville, Mississippi and the Tennessee Valley Authority, Muscle Shoals, Alabama.

The author worked for about four months after graduation as an engineer for the Florida Board of Conservation, Division of Water Resources, Tallahassee, Florida. He then returned to Mississippi where he has since been employed by the Agricultural Research Service, USDA National Sedimentation Laboratory, Oxford, Mississippi.

The author's primary research has been in the area of conservation tillage with emphasis on erosion evaluation and prediction. He has also conducted research on the relationship between rainfall intensity and kinetic energy of storm rainfall and on evaluation of the rainfall erosion index factor for use in the universal soil loss equation. He complemented his research program with further graduate study and received the Master of Science degree in Agricultural Engineering from North Carolina State University in 1977.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

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Title of Dissertation: Effects of Straw Residues on Soil Erosion

Approved:

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Date of Examination:

November 21, 1986